Technical and Regulatory Review and Benchmarking of Air Emissions from Alberta's Kraft Pulp Mills

Alberta Environment

Technical and Regulatory Review and Benchmarking of Air Emissions from Alberta's Kraft Pulp Mills

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TABLE OF CONTENTS

LIST OF TABLES v
LIST OF FIGURES vi
GLOSSARY vii
SUMMARY xii

1.0 Introduction 1
1.1 Objective 1
1.2 Report Structure 1
1.3 Assumptions and Limitations 2
2.0 Benchmarking Alberta's Kraft Mills 4
2.1 Alberta Kraft Pulp Mill Descriptions 4
2.1.1 Boyle 4
2.1.2 Grand Prairie 5
2.1.3 Hinton 5
2.1.4 Peace River 6
2.1.5 Tabulation of key Alberta kraft mill systems affecting air emissions 6
2.2 Benchmarking of Air Emission Permit Limit Values 8
2.2.1 Tabulation of Alberta kraft mill permit limit values 8
2.2.2 Tabulation of emission limits from Standards, Guidelines and Regulations 9
2.2.3 Benchmarking Alberta kraft mill permits 12
2.3 Benchmarking Air Emission Discharges 13
2.3.1 Source emission benchmarking - 2005 14
2.3.1.1 Benchmarking discharges - Recovery Boiler 17
2.3.1.2 Benchmarking discharges - Smelt Dissolver 18
2.3.1.3 Benchmarking discharges - Lime Kiln 19
2.3.1.4 Benchmarking discharges - Wood-fired Power Boiler 20
2.3.1.5 Source emissions of some recent world class mills 21
2.3.2 Mill wide emission benchmarking - 2005 Data 22
2.3.2.1 Mill wide emissions of Albertan, Canadian, Swedish and Finnish Mills 22
2.3.2.2 Mill wide emissions of some recent world class mills 24
3.0 Technology Used in New World Class Kraft Pulp Mill Designs 27
3.1 Terminology 27
3.2 Accepted Modern Technology and Best Available Techniques 29
4.0 Odorous Gas Venting 32
4.1 Description 32
4.2 Regulatory Approaches to Venting 33
4.2.1 Alberta 33
4.2.2 The US 33
4.3 Benchmarking Venting Durations 34
4.3.1 Alberta mills 34
4.3.2 Some newer mill results 35
5.0 Overview of Key Regulations Elsewhere 38
5.1 Introduction 38
5.2 US Regulations 39

5.3 EU Regulations 40
5.4 World Bank Regulations 42
6.0 CO_2 Emissions and Energy Efficiency 43
6.1 Energy Conservation and Benchmarking 43
6.1.1 What can be done in existing mills now? 44
6.2 Current Best Practice in Newer Mills 46
6.2.1 Best design practice 46
6.2.2 Benchmarking some recent world class mills 47
Appendix A - Air Emission Regulations and Management Measures 51
A - 1 Introduction 51
A - 2 Regulations in the Canadian Provinces of BC, Ontario and Quebec 51
A - 2.1 Federal and Provincial Regulatory Approaches 51
A - 2.2 Provincial Regulatory Process 52
A - 2.2.1 General ***52***
A - 2.2.2 Contaminants of interest ***53***
A - 2.3 British Columbia 55
A - 2.4 Ontario 57
A - 2.5 Quebec 59
A - 2.6 Comparison of AB, BC, ON and QC limits 61
A - 2.7 Kraft Mill Odour Abatement Requirements in Selected Provinces 68
A - 3 Regulations in the US 69
A - 3.1 Regulatory Approach 69
A - 3.2 Permitting Process 70
A - 3.3 New Source Performance Standards (NSPS) 73
A - 3.3.1 Kraft pulp mills ***73***
A - 3.3.2 Power boilers ***75***
A - 3.4 National Emission Standards for HAPs and MACT Limits 76
A - 3.4.1 MACT I ***77***
A - 3.4.2 MACT II ***78***
A - 3.4.3 MACT III ***79***
A - 3.4.4 MACT for industrial boilers and heaters ***80***
A - 3.4.5 MACT standards for monitoring and reporting ***82***
A - 4 Regulations in the EU 82
A - 5 Regulations in Sweden 85
A - 6 Regulations in Finland 86
A - 7 Regulations of the World Bank 88
A - 8 Emission Limit Comparison for Selected Jurisdictions 90
Appendix B - Mill Processes, their Air Emissions and Controls 95
B - 1 Introduction 95
B - 2 Overview of Pulp and Paper Manufacturing 95
B - 2.1 Fibre Supply, Wood and Chip Handling and Storage 95
B - 2.2 Chemical Pulp Manufacture 96
B - 2.3 Mechanical Pulp Manufacture 97
B - 2.4 Paper and Paperboard Manufacture 98
B - 2.5 Steam and Power Supply 98
B - 2.6 Effluent Treatment and Fugitive and Other Sources 99

B - 3 Kraft Pulping 99
B - 3.1 Pulping and washing *99*
B - 3.1.1 Batch and continuous pulping ***99***
B - 3.1.1.1 Description of process99 ..... **111**
B - 3.1.1.2 Air emission sources ***100***
B - 3.1.1.3 Emission controls ***101***
B - 3.1.2 Washing ***103***
B - 3.1.2.1 Description of process ***103***
B - 3.1.2.2 Air emission sources ***104***
B - 3.1.2.3 Emission controls ***105***
B - 3.1.3 Oxygen Delignification ***105***
B - 3.1.3.1 Description of process ***105***
B - 3.1.3.2 Air emission sources ***105***
B - 3.1.3.3 Emission controls ***106***
B - 3.2 Black Liquor Evaporation *106*
B - 3.2.1 Evaporators ***106***
B - 3.2.1.1 Description of process ***106***
B - 3.2.1.2 Air emission sources ***107***
B - 3.2.1.3 Emission controls ***108***
B - 3.2.2 Condensate Stripping ***108***
B - 3.2.2.1 Description of process ***108***
B - 3.2.2.2 Air emission sources ***109***
B - 3.2.2.3 Emission controls ***110***
B - 3.3 Chemical Recovery *110*
B - 3.3.1 Chemical Recovery Boiler ***110***
B - 3.3.1.1 Description of process **110**
B - 3.3.1.2 Air emissions **115**
B - 3.3.1.3 Air emission estimates and control strategies **118**
B - 3.3.2 Smelt Dissolving Tank ***123***
B - 3.3.2.1 Description of process **123**
B - 3.3.2.2 Air emission estimates and control strategies **123**
B - 3.4 Causticizing and Lime Burning *124*
B - 3.4.1 Causticizing ***124***
B - 3.4.2 Lime Burning ***125***
B - 3.4.2.1 Description of process **125**
B - 3.4.2.2 Air emission sources and control strategies **125**
B - 4 Mechanical Pulping 130
B - 4.1 Pulping *130*
B - 4.1.1 Description of process ***130***
B - 4.1.2 Air emission sources and control strategies ***131***
B - 4.2 Bleaching *132*
B - 4.2.1 Description of process ***132***
B - 4.2.2 Air emission sources and control strategies ***133***
B - 5 Paper Machines and Pulp Dryers 133
B - 5.1 Description of process *133*
B - 5.2 Air emission sources *134*
B - 6 Power Boilers, Combustion Turbines, Effluent Treatment and Other Sources ... 134
B - 6.1 Power Boilers – Wood Waste and Fossil Fuel Fired *134*
B - 6.1.1 Description of process ***134***
B - 6.1.2 Air emission sources and control strategies ***137***

B - 6.2 Wood Waste Fuel Dryer *142*
B - 6.2.1 Description of process ***142***
B - 6.2.2 Air emission sources and control strategies ***142***
B - 6.3 Cogeneration and Combustion Turbines *143*
B - 6.3.1 Description of process ***143***
B - 6.3.2 Air emission sources and control strategies ***144***
B - 6.4 Effluent Treatment *145*
B - 6.4.1 Description of process ***145***
B - 6.4.2 Air emission sources and control strategies ***146***
B - 6.5 Fugitive, Diffuse and Miscellaneous Sources *147*
Appendix C - Air Emission Control Measures and their Costs **152**
C - 1 Background and Assumptions 152
C - 2.1 Basis of Cost Estimates *152*
C - 2 Wood Handling and Storage 154
C - 3 Chemical Pulping 154
C - 4 Mechanical Pulping 157
C - 5 Bleaching 157
C - 6 Chemical Recovery – Kraft 157
C - 6.1 Kraft Recovery Boiler *157*
C - 6.2 Smelt Dissolving Tank *160*
C - 7 Lime Kiln 161
C - 8 Power Boilers 162
C - 9 Effluent Treatment 166
C - 10 Comparison of Estimated Cost per Tonne Contaminant Removed 167
Appendix D - Conversion of Units **172**
D - 1 Introduction 172
D - 2 Standard Dry Conditions 172
D - 3 Volume to Weight 173
D - 4 Reference Oxygen 173
D - 5 Specific Flue Gas Volume Rates 174
D - 5.1 Power Boilers *174*
D - 5.2 Recovery Boilers *174*
D - 5.3 Smelt Dissolving Tank *175*
D - 5.4 Lime Reburning *175*

LIST OF TABLES

Table 1 Key Equipment and Systems Affecting Air Emissions in 2005 23
Table 2 Air Emission Permit Limit Values - Permit Units 23
Table 3 Air Emission Permit Limit Values - Mass/Volume Concentration Units 24
Table 4 Emission Permit Limit Comparison for Selected Jurisdictions - Expressed in the Units used in Alberta 25
Table 5 Alberta Kraft Mill Air Emissions - Expressed in Concentration - 2005 30
Table 6 Approximate Conversion Factors Used 32
Table 7 Best Current Practice - Source Concentrations Expressed in the Units and Reference Oxygen Content Used by Alberta Environmen 39
Table 8 Comparison of Best Current Practice - Mill Wide Emissions 41
Table 9 AMT for the Reduction of Emission to the Atmosphere 47
Table 10 Monthly Permitted Venting Limits - Concentrated NCG 53
Table 11 Monthly Permitted Venting Limits - Dilute NCG 53
Table 12 MACT Requirements for NCG Incineration Performance 53
Table 13 Annual Venting Time - Concentrated NCG 54
Table 14 Annual Venting Time - Dilute NCG 54
Table 15 CNCG Venting by Three Swedish Pulp Mills 55
Table 16 CNCG and DNCG Venting from Four Older US Pulp Mills 56
Table 17 Steam and Power Use in Recent New Bleached Kraft Pulp Mill Designs 69
Table 18 Approach to Air Emission Regulations 83
Table 19 Ambient Air and Point-of-Impingement Guidelines 84
Table 20 Duration of Permit Validity 83
Table 21 Ontario Interim Design and Review Guideline for Woof-fired Combusters - Clean Wood Only 89
Table 22 TRS Emission Limits for New Sources 92
Table 23 TRS Emission Limits for Existing Sources 92
Table 24 Particulate Emission Limits for New Sources 93
Table 25 Particulate Emission Limits for Existing Sources 94
Table 26 Boiler Regulations NO_x and SO_2 95
Table 27 Provincial Ambient Air Criteria 96
Table 28 POI Regulated Limits 96
Table 29 Federal Ambient Air Objectives 97
Table 30 Canada Wide Standards for Ozone and $PM_{2.5}$ 97
Table 31 CNCG Requirements for Existing Mills 99
Table 32 DNCG Requirements for Existing Mills 99
Table 33 PSD Significant Emission Rates 102
Table 34 NSPS Limits for Industrial Boilers - Subpart Db 106
Table 35 Summary of Promulgated MACT II Standards for Combustion Sources 110
Table 36 Proposed MACT for Solid Fuel Boilers and Process Heaters 112
Table 37 Proposed MACT for Liquid Fuel Boilers and Process Heaters 112
Table 38 Preliminary Air Emission Permit in a Swedish BKP Mill 117
Table 39 Preliminary Air Emission Permit in a Finnish BKP Mill 119
Table 40 World Bank Air Emission and Energy Guidelines for Kraft Pulp Mills 121
Table 41 Emission Limit Comparison for Seleted Jurisdictions 123

Table 42 Kraft Fibreline and Miscellaneous Emission Control Measures 193
Table 43 Kraft Fibreline and Miscellaneous Source Emission Control Costs 194
Table 44 Recovery Boiler TRS and PM Emission Control Measures 196
Table 45 Recovery Boiler Emission Control Costs 197
Table 46 Smelt Dissolving Vent Emission Control Measures 198
Table 47 Smelt Dissolving Vent Emission Control Costs 199
Table 48 Lime Kiln PM Emission Control Measures 200
Table 49 Lime Kiln Emission Control Costs 200
Table 50 Power Boiler NO_x Emission Control Measures 201
Table 51 Power Boiler NO_x Emission Control Costs 202
Table 52 Power Boiler PM Emission Control Measures 203
Table 53 Power Boiler Emission Control Costs 203
Table 54 Effluent Treatment TRS Emission Control Measures 205
Table 55 Effluent Treatment TRS Emission Control Costs 205

LIST OF FIGURES

Figure 1 Recovery Boiler Permit Limit Values for PM and TRS 27
Figure 2 Smelt Dissolver Permit Values for PM and TRS 28
Figure 3 Lime Kiln Permit Limit Values for PM and TRS 28
Figure 4 Wood-fired Power Boiler Permit Limit Values for PM 29
Figure 5 Recovery NO_x and PM 33
Figure 6 Recovery SO_2 and TRS 33
Figure 7 Smelt Dissolver - PM and SO_2 34
Figure 8 Smelt Dissolver - TRS 35
Figure 9 Lime Kiln NO_x and PM 35
Figure 10 Lime Kiln SO_2 and TRS 36
Figure 11 Wood-fired Power Boiler - NO_x and PM 37
Figure 12 Wood-fired Power Boiler - SO_2 37
Figure 13 Mill Wide Benchmarking - PM 42
Figure 14 Mill Wide Benchmarking - SO_2 43
Figure 15 Mill Wide Benchmaking - TRS 44
Figure 16 CNCG Venting Times Compared with US and Swedish 56
Figure 17 Main Air Emission Sources and NCG Controls - Example 135
Figure 18 Contaminant Removal Cost per tonne for Selected Generic Emission Reduction Measure by Emission Type - Illustrative Example 207

GLOSSARY

a	annum, year
A	Actual (A) as in gas volume at actual conditions (vs Standard conditions), or air as in Air Dried (AD) referring to pulp moisture content
AAQ	ambient air quality
AD	air dry, by definition for pulp contains 10% moisture & 90% bone dry pulp.
ADt	air dry metric tonnes (2205 lb)
ADt/a	air dry metric tonnes per annum
ADt/d	air dry metric tonnes per day
ADUt/d	air dry unbleached metric tonnes per day
Am^3	volume in cubic metres at the actual wet conditions of the gas
ADm^3	dry volume in cubic metres at the actual conditions of the gas
BATEA	Best Available Technology Economically Achievable
BACT	best available control technology
BC-BACT	best available control technology in British Colombia, which for purposes of this report is defined in the draft B.C. MELP document of 16 November 1993
BCTMP	bleached chemi-thermo-mechanical pulp
BD	bone dry synonymous with oven dry, OD
BDt	bone dry metric tonne (same as oven dry)
BDt/d	bone dry metric tonne per day
BL	black liquor
BLS	black liquor solids, bone or oven dry
BREF	European Union IPPC - BAT reference document
BSW	brown stock washer
Btu	British thermal unit
CCA	Clean Condensate Alternative
CEM	continuous emission monitoring
CFM	cubic feet per minute
CH_3OH	methanol
CH_3SH	methyl mercaptan
CH_3SCH_3	dimethyl sulphide
CH_3SSCH_3	dimethyl disulphide
Cl_2	chlorine
ClO_2	chlorine dioxide
ClO_3	chlorate ion
CNCG	Concentrated non condensable gases
CTMP	chemi-thermo-mechanical pulp
^oC	degrees celsius

d	day
D	dry gas conditions or chlorine dioxide bleaching stagedepending on the context
DCE	direct contact evaporator (see also NDCE)
DNCG	Dilute non condensable gases
DS	dry solids
d/a	days per annum
ESP	electrostatic precipitator
EHS	Environmental, Health, and Safety Guidelines of the World Bank
ft^3	cubic feet
g	gram
G	giga, 10^9
GJ	gigajoule
h	hour
h/a	hours per year
HAP	hazardous air pollutants, which has a specific meaning in U.S. jurisdictions described in Section 3
HC	high consistency
H_2O_2	hydrogen peroxide
H_2S	hydrogen sulphide
IPPC	European Commission's Integrated Pollution Prevention and Control
IPPC-BAT	Best Available Techniques as defined by the EU's Integrated Pollution Prevention and Control policies
ISO	International Standards Organization
k	kilo, 10^3
kg	kilogram
kg/ADt	kilograms per air dry metric tonne
kJ	kilojoule
kPa	kilopascal
kPag	kilopascal gauge
kW	kilowatt
kWh	kilowatt hour
LAER	Lowest Achievable Emission Rating as defined by the US EPA
lb	pound
lbDS	lb dry solids in the present context referring to black liquor and synon-ymous with lbBLS
lbBLS	lb black liquor solids on a dry basis, synonymous with lbDS
LP	low pressure, usually referring to steam
MACT	Maximum Achievable Control Technology as defined by the US EPA
MBtu	million British thermal units
MCR	maximum continuous rating of a boiler or 100 % of nameplate rating
m	metre

M	mega, 10^6
MJ	megajoule
MP	medium pressure, usually referring to steam
MW	megawatt
mg	milligram
min.	minute
m^3	cubic metre
m^3/ADt	cubic metre per air dry metric tonne
m^3/d	cubic metre per day
m^3/h	cubic metre per hour
N	normal conditions, an SI standard of 0°C and 101.325 kPa
Na_2S	sodium sulphide
Na_2SO_4	sodium sulphate, or saltcake
NCASI	National Council of the Paper Industry for Air and Stream Improvement Inc.
NCG	non-condensable gas
NDCE	non-direct contact evaporator (see also DCE)
NESHAP	National Emission Standards for Hazardous Air Pollutants
ng	nanogram, 10^{-9}g
NO	nitric oxide
NO_x	nitrogen oxides
N_2O	nitrous oxide
NO_2	nitrogen dioxide
NSPS	New Source Performance Standards as defined by the US EPA
NSR	New Source Review (see regulations section) as defined by the US EPA
OD	oven dry, synonymous with bone dry (BD)
O_2	oxygen
O_3	ozone
P	hydrogen peroxide designation in bleaching sequences.
Pa	Pascal, unit of pressure
PAH	polynuclear aromatic hydrocarbons
PB	abbreviation for power boiler
PCB	polychlorinated biphenyls
PCDD	polychlorinated dibenzo-p-dioxins
PCDF	polychlorinated dibenzofurans
PCDD/F	polychlorinated dibenzo-p-dioxins and furans
pH	relative acidity or alkalinity
PM	Particulate matter and taken to mean total particulate matter if unqualified
POI	Point of impingment on the ground of a stack plume
ppb	parts per billion, 10^9
ppm	parts per million, 10^6

ppm_{DV}	parts per million dry volume basis
PSD	Prevention of Significant Deterioration
psig	pounds per square inch gauge
RACT	Reasonably Achievable Control Technology
s	second
S	sulphur, or, standard gas conditions of temperature and pressure as specified, eg: 20°C and 101.325 kPa, depending on the context
SCR	Selective catalytic reduction
SD	Standard (refer abbreviation S), dry
SEPA	Swedish Environmental Protection Agency
SIP	U.S. State Implementation Plan
SNCR	Selective non catalytic reduction
SOG	stripper off-gases
SO_2	sulphur dioxide
SO_3	sulphur trioxide
SO_x	sulphur oxides
SSM	Start-up, Shutdown and Malfunction (see Section 4.2.2)
STFI	Swedish Forest Products Research Laboratory
SWD	softwood
t	metric tonne (2205 lb)
T	short ton (2000 lb)
TAPPI	Technical Association of the U.S. Pulp and Paper Industry
TGNMO	total gaseous non-methane organic
TIC	total installed cost
TMP	thermo-mechanical pulp
TRS	total reduced sulphur
tBLS	tonne black liquor solids on a dry basis, synonymous with tDS
tDS	tonnes dry solids, in the present context referring to black liquor and synonymous with tBLS
t/ADt	metric tonnes per air dry metric tonne
t/a	metric tonnes per annum (year)
t/d	metric tonnes per day
t/h	metric tonnes per hour
USgal	U.S. gallons
US	United States of America
US EPA	United States Environmental Protection Agency
US-BACT	best available control technology per the US EPA definition
VOC	volatile organic compound
W	watt
WBG	World Bank Group
Z	bleaching stage using ozon

%	percent
% O_2	reference oxygen conditions in percent by volume dry basis
µg	microgram, 10^{-6}g
$	Canadian Dollars
$M	millions of Canadian dollars
$k	thousands of Canadian dollars
$US	U.S. dollars

SUMMARY

The Environmental Policy Branch of Alberta Environment (AB Environment) requires a study of emission limits and control technologies for pulp and paper mills and issued a request for proposal on 13 April 2007. The purpose of the study is to compare the Alberta regulations and actual mill emissions performance relative to international standards, with a view to furthering environmental performance.

The scope includes benchmarking the Alberta mills against other mills in selected jurisdictions, describing best available processes and emission control technologies with specific attention to odorous gas venting, reviewing air emission guidelines and standards in relevant jurisdictions, and identifying any "early wins" that would improve the environmental performance while providing economic benefits.

The study is limited to the kraft pulp mills of Alberta. Initial investigation of permits showed that the main sources of emissions of concern such as particulate matter (PM), nitrogen oxides (NOx), sulphur gases (odour and SO_2) were the four kraft pulp mills. The other mills comprising two mechanical pulp mills, and the sole newsprint mill would represent small sources in comparison. In addition, as these three mills are not required to submit emission data to AB Environment, no benchmarking data is available. AB Environment staff therefore agreed that study effort should concentrate on the Alberta kraft pulp mills. These are located at Boyle, Grand Prairie, Hinton and Peace River.

Benchmarking (Section 2) The benchmarking of Alberta's kraft mill permit limit value was carried out against the limits specified in standards and guidelines of demanding jurisdictions today. These standards and guidelines for new mills are taken as reflecting best current practice permits. The comparison shows that best current practice PM limits from all combustion sources are a small fraction of those of the Alberta mills, while TRS limits from all sources are more comparable. Given the introduction of much tighter limits on very fine particulate matter ($PM_{2.5}$) in the last decade, this performance gap is not surprising, since the most recent of the Alberta mills, the mill at Boyle, was designed and built over 15 years ago. It is noted that the better PM emission performance of new mills and rebuilds in recent years is due more to making the investment in better add-on controls rather than signaling any advance of technology or in-process control.

Turning to benchmarking actual emission performance, source emission sampling data submitted to Alberta Environment for 2005 was assembled for the four Alberta kraft mills, as was data for a number of selected Canadian and US kraft pulp mills. While Finland and Sweden publish emission data, they do so only on a mill wide basis and so, without data on individual sources, they could not be included.

The data within each group was ranked by magnitude and is presented in graphical form with the data for each Alberta mill labeled. A graphical presentation was selected to bring out any clear overall pattern, but none was apparent. The high degree of scatter reflects the wide range of technological age and degrees of modernization of these Canadian and US mills.

However, some very general comments can be made. NO_x results for the Alberta mills generally are in line with Canadian and US mills for all sources. PM for the Alberta mills is generally comparable or somewhat lower than the median value for the Canadian and US mills depending on the source. For SO_2, the Alberta kraft mill data is sparse for some sources; values are perhaps comparable though in the case of the two Power Boilers for which data exists, the values are much higher than that of the Canadian and US mills. A standout is TRS from Alberta kraft mills which is significantly lower for all sources than the Canadian and US mills. Reasons for this have not been investigated.

Technology Used In New World Class Kraft Pulp Mill Designs (Section 3)
There is relatively little difference in the process technologies and scope requirements between what is termed in the EU as Best Available Techniques and in the Tasmanian Governments Accepted Modern Technology. The process technologies and scope requirements described are typically used in new world class kraft pulp mills being built today. These include: collection and incineration of concentrated and dilute sulphur-based odorous gases, with backup incineration systems for the concentrated ones; computerized combustion control of the recovery boiler and lime kiln to limit CO, and NOx and other emissions; firing high solids black liquor in the recovery boiler, to name some key measures. This section assumes the reader is familiar with pulp and paper processes and air emission control technologies; for further detail, the reader is referred to Appendix C - Mill Processes, their Air Emissions and Controls.

Odorous Gas Venting (Section 4) Historically, the strong odour of the sulphur-based gases have been one of the most characteristic and negative features of a kraft pulp mill to humans. Thus, although venting only occurs very occasionally during process upsets, the sharp increase in odour levels that result can make them a public issue. This section compares the Alberta mill results with best current practice and venting regulations. The direct comparison of venting times the Alberta kraft pulp mills are allowed under their permits with the US regulations is not possible since the latter exclude venting during process upsets, which is not the case for the Alberta mills. Process upsets for this rule are defined to include start-ups, shutdowns and malfunctions. It is acknowledged that the wording of certain Alberta kraft pulp mill permits leaves room for some ambiguity in what is included in venting time, but in general venting during all start-up, shutdown and malfunctions is counted toward the permit limit.

Actual Alberta mill venting durations in 2005 were a small fraction of that allowed by the respective permits. Noteworthy is that the two Alberta mills with best venting time the performance compared well with some limited Swedish mill data available, the basis of both being that venting during process upsets is included.

Overview of Key Regulations Elsewhere (Section 5) The regulations affecting pulp and paper mills in the US, the EU, and the guidelines for the World Bank are at the forefront of pulp and

paper regulations worldwide. This section provides a brief outline of the regulatory process behind the guideline limit values tabulated in Section 2. More detailed information on these and the other jurisdictions of British Columbia, Ontario and Quebec, Finland, and Sweden are presented in Appendix B - Air Emission Regulations and Management Measures.

CO_2 Emissions and Energy Efficiency (Section 6) This section addresses the emissions and control of the principal greenhouse gas, CO_2. Since the carbon in biomass materials is of biogenic origin and part of a natural cycle, the associated CO_2 releases are not included in greenhouse gas emissions. It is the combustion of non-renewable fossil fuels such as gas, oil and coal in the pulp and paper industry that is responsible for virtually all of the additions to greenhouse gases. These consist primarily of CO_2. Accordingly, non-renewable CO_2 emissions control focuses on reducing the use of fossil fuels. This is achieved by the displacement of fossil fuels by biomass fuels, and using energy more efficiently. The section outlines approaches that include energy consumption benchmarking, energy conservation measures for existing mills, an outline of Pinch Analysis. It also presents data on best current design practice and energy consumption performance for some recent world class mills.

In terms of "Early Wins", the most apparent potential is in CO_2 emission reduction where economic gains can result from the reduced use of fossil fuels. Experience shows that there are often many energy conservation measures that involve little or no investment, such as improved operating procedures or the undertaking of energy audits which uncover unintended or hidden energy waste, all of which generally translate into fossil fuel and money saved, and reduced non-renewable CO_2 emissions. It is noteworthy that in 1975 shortly after the first oil crisis the Swedish kraft industry started to undertake industry-wide energy audits (detailed to the department level) every 5 years to benchmark progress and focus attention on an important issue for a country with no oil or gas resources of its own. This strategy has stood their industry in good stead over the years and motivated improvement.

1.0 INTRODUCTION

Alberta Environment issued a request for proposal and terms of reference for a study of emission limits and control technologies for pulp and paper mills on 13 April 2007. The scope was to:

- Review air emission standards for Alberta, BC, Quebec, Ontario, the US, Sweden, Finland, and the EU;
- Identify best available technology;
- Identify methods to address venting; and
- Outline low cost control measures, and identify any "early wins" that combine improved environmental performance with economic benefits.

On 12 June 2007, Bruce Process Consulting Ltd. was retained to carry out the study.

1.1 Objective

The purpose of the study is to provide the technical background needed to assist Alberta Environment when considering setting air emission standards for new mills. Also it is to provide an assessment of the air emission performance of Alberta's mills both in terms of existing mills and new world class mills elsewhere.

The study approach is to present available mill air emission performance data in selected jurisdictions locating the Alberta mills therein, to describe the technology used in new world class mills, to provide an overview of pulp and paper regulations in selected jurisdictions, to outline non-renewable carbon dioxide (CO_2) emission reduction measures, and to identify "early wins" and achievable options to reduce emissions.

1.2 Report Structure

The wide scope of the study has meant that to focus on the most relevant information in the main report, a significant amount of detailed information is presented in appendices. Thus the body of the report concentrates on the important matters of benchmarking emission performance of the Alberta mills, establishing the performance of world class mills today, venting of untreated non condensable gases (NCG), providing an overview of regulations in key jurisdictions, and discussing CO_2 and energy efficiency.

The second section addresses the benchmarking of Alberta's kraft mills, describes the main features of the Alberta mills, and benchmarks their air emissions against mills of a similar age, and against new world class kraft pulp mills being designed today.

Section 3 summarizes the technology and key design features of the new world class kraft pulp mills being built today. It introduces some of the terminology used such as Best Available

Techniques (BAT) adopted in the EU and Best Available Control Technology (BACT) used in the US. This section assumes the reader is familiar with pulp and paper processes and air emission control technologies; further detail and background is provided in Appendix C - Mill Processes, their Air Emissions and Controls.

Section 4 describes why the venting of odorous gases occurs, tabulates venting data for Alberta kraft pulp mills and compares the results with some data on best current practice and venting regulations.

Section 5 briefly summarizes regulations in the US, the EU, and the guidelines for the World Bank, all of which are at or near the forefront of pulp and paper regulations worldwide. More detailed information on these and the other jurisdictions of British Columbia, Ontario and Quebec, Finland, and Sweden are presented in Appendix B - Air Emission Regulations and Management Measures.

Section 6 addresses the control of greenhouse gas emissions from non-renewable sources which amounts to measures to reduce the use of fossil fuels through energy conservation and fuel substitution.

1.3 Assumptions and Limitations

The pulp and paper mills in Alberta comprise:

- 4 - kraft pulp mills.
- 2 - mechanical pulp mills, and
- 1 - newsprint mill

The scope listed emissions of carbon dioxide (CO_2), particulate matter (PM), fine particulate matter (PM_{10}), very fine particulate matter ($PM_{2.5}$), nitrogen oxides (NOx), sulphur dioxide (SO_2), volatile organic compounds (VOC), ammonia (NH_3) and total reduced sulphur (TRS).

Initial investigation of the Alberta mill permits showed that the main sources of emissions of concern such as particulate matter (PM), nitrogen oxides (NOx), sulphur gases (odour and SO_2) were the four kraft pulp mills, since the two mechanical pulp mills, and the sole newsprint mill were not required to submit emission data to AB Environment. Accordingly, it was agreed with AB Environment staff to focus study effort solely on the kraft pulp mills in the province.

Alberta Environment agreed that the focus of CO_2 emissions control should be fossil fuel-related emissions of CO_2 which would be discussed in terms of fuel substitution and energy efficiency, since this t is the primary route to control these emissions. The discussion of energy efficiency and pinch analysis is relegated to Section 6 in the report. Of these emission types, NH_3 appears in only one air permit, that of the Slave Lake Pulp mill and is related to ammonia storage system. The ammonia is used as a nutrient in the effluent treatment system and, except for accidental releases, would not be a source of emission. Because of the nature of the source, ammonia emissions are is not included in the study. In addition, the distinction between total, fine and very fine particulate matter (PM / PM_{10} / $PM_{2.5}$) is not relevant to benchmarking since the

benchmarking information available for the Alberta kraft mills all relates to total particulate, or PM, as does available benchmarking data from other mills. Accordingly there is little specific reference to fine and very fine particulate matter as opposed to total PM.

Only technology in common use within the industry is referenced, though emerging technology encountered in the work is mentioned if potentially relevant to the levels being contemplated for emission criteria and guidelines.

This study assumes that the source sampling test methods and analytical procedures among jurisdictions and countries do not differ sufficiently to invalidate data comparisons.

The estimates of cost in Appendix D have been prepared using literature sources and in-house information where appropriate data was available. The cost estimates are presented to allow very preliminary comparison of costs of emission control options. In the limited number of comparisons between in-house cost data and literature-based costs, the latter were shown in some cases to be low estimates by a wide margin. In any formal screening of control alternatives, estimates based on preliminary engineering of the facility or control system are required, taking into account site-specific factors. However, it is expected that in most cases, the cost estimates presented in this report are illustrative of the order of magnitude of total installed costs that can be expected in Canada in 2007. There may be substantial differences between the costs presented here and the costs for a particular installation as estimated during definition engineering.

2.0 BENCHMARKING ALBERTA'S KRAFT MILLS

This section presents available information on the Alberta mills, and benchmarks air emissions in terms of both the current permit limit values and the discharge concentrations or mass emission rates against mills of a similar age, and against new world class kraft pulp mills being designed today.

2.1 Alberta Kraft Pulp Mill Descriptions

The pulp and paper mills in Alberta comprise:

- 4 - kraft pulp mills — Boyle, Grand Prairie, Hinton and Peace River
- 2 - mechanical pulp mills — Slave Lake Pulp and Whitecourt
- 1 - newsprint mill — Alberta Newsprint

Since the emissions from mechanical pulp mills and newsprint mills are not regulated in any jurisdiction, aside from any combustion equipment, benchmarking was not carried out.

The fibreline and papermaking emissions from mechanical pulp mills and newsprint mills consist mainly of PM and VOC and are not considered significant and accordingly are not believed to be regulated in any jurisdiction. For this reason, descriptions for these mills were not obtained nor was any benchmarking carried out. However, the emissions from fuel fired heaters and boilers are significant but differ little from the description of power boilers presented in Appendix C - Mill Processes, their Air Emissions and Controls, subsection C – 6.

Accordingly, the mill description and benchmarking in this section is limited to the four kraft pulp mills.

2.1.1 Boyle

The Alberta-Pacific bleached kraft market pulp mill produced 663 000ADt of hardwood and softwood pulp in 2005, an average rate of about 1850ADt/d. The mill started up in 1993.

The recovery boiler is a 900psig unit designed to fire 2639tBLS/d black liquor solids. Currently black liquor is fired at 75% solids concentration.

The single 900psig power boiler is a combination wood / gas fired unit. There are two 41MW extraction-back pressure steam turbine generators.

Concentrated non condensable gases (CNCG) along with stripper off-gases (SOG) are fired in the power boiler with backup in the kiln. Collected dilute non condensable gases (DNCG) are fired in the recovery boiler with firing in the power boiler as backup or, only in the case of emergencies, by venting into the main boiler stack.

2.1.2 Grand Prairie

The Weyerhaeuser bleached kraft market pulp mill produced 360 000ADt of softwood pulp in 2005, an average rate of about 1030ADt/d. The greenfield mill started up in 1973.

The recovery boiler is a 900psig unit designed to fire 1753tBLS/d at 70% solids concentration. The recovery boiler electrostatic precipitator was upgraded prior to 2005.

The single 900psig power boiler is a combination wood / gas fired unit. There is a TransCanada Energy combined cycle (gas turbine and steam turbine generator) power plant located beside the mill site, which supplies medium and low pressure steam to the mill. There is also a high pressure header between the two steam systems. The power plant has a double-extraction condensing type steam turbine. Power excess to mill needs is sold into the Alberta power grid when it is economically justified.

CNCG along with stripper off-gases (SOG) are fired in the kiln with firing in the power boiler as backup. DNCG are fired in the recovery boiler with backup incineration in the power boiler or in emergency situations vented via the main stack.

A new 1500psig recovery boiler of 2200tBLS/d and new electrostatic precipitator was started up in the spring of 2007. The new boiler is designed to fire black liquor at 80% solids. The smelt dissolving tank vent gases and dilute NCG are introduced into the combustion air system after conditioning and incinerated in the recovery boiler.

Given that these changes occurred after 2005, the emission data for the Grand Prairie mill reflect the mill with the original recovery boiler.

2.1.3 Hinton

The Hinton Pulp, division of West Fraser Mills Ltd., is a bleached kraft market pulp mill and produced 430 000ADt of hardwood and softwood pulp in 2005, an average rate of about 1200ADt/d. The mill started up in 1957.

There are two recovery boilers operating in parallel, and firing black liquor at 70% solids. The mill undertook a major rebuild in 1989 involving changes to the digesting, bleaching, addition of oxygen delignification and replacement of #1 Recovery Boiler and addition of #3 Recovery Boiler. The two operating recovery boilers are now #2, a CE unit of 1200tBLS/d installed in 1979, and the #3 which is a CE unit of 1350tBLS/d.

There are two power boilers, #2 Power Boiler firing gas only and #3 Power Boiler, firing wood and gas. #3 Power Boiler is the converted #1 recovery boiler and uses a travelling grate for wood waste firing.

CNCG is collected and incinerated along with stripper off-gases (SOG) in the lime kiln or #2 Power boiler or #3 Power Boiler. DNCG is collected and incinerated in either #2 Power Boiler or #3 Power Boiler.

2.1.4 Peace River

The Daishowa-Marubeni bleached kraft market pulp mill produced 494 200ADt of hardwood and softwood pulp in 2005, an average rate of about 1380ADt/d. The mill started up in 1990.

The recovery boiler is a 900psig unit is designed to fire 2200tBLS/d black liquor solids. Currently black liquor is fired at 75% solids concentration.

The single 900psig power boiler is a combination wood / gas fired unit. There is a single 40MW extraction-back pressure steam turbine generator.

CNCG along with stripper SOG are fired in the kiln with firing in the power boiler as backup. DNCG are fired in the recovery boiler with firing in the power boiler as backup or, in emergency situations, venting from the stack top.

2.1.5 Tabulation of key Alberta kraft mill systems affecting air emissions

The principal mill systems in operation in 2005 and affecting air emissions for that year in the four Alberta kraft mills are presented in Table 2.1.

Table 2.1 – Key Equipment and Systems Affecting Air Emissions in 2005

	Boyle	Grand Prairie	Hinton	Peace River
RECOVERY BOILER				
Number in service	1	1	2	1
Number retired from service	0	0	0	0
Number converted to power boilers	0	0	1	0
No. 1 Unit				
Year of start-up	1993	1973	1980 (RB2)	1990
tBLS/d or MMlbBLS/d	2639	1754	3 MMlb/d	2085 tBLS
% solids as fired	74%	70-71%	70%	75% HW, 70% SW
Steam conditions psig/°F	6309kpag/454 °C	1500/900/795°F	600 psi / 750°F	6434 kPa / 434°C
Cascade / cyclone or evap. + concen.?	evap. + conc.	evap. + conc.	evap. + conc.	evap. + conc.
Date of last major ESP upgrade	none	1990	2002	none
Year new ESP installed	1993		2000	1990
Year combustion air system upgrade installed	none	1990/1995/1997/ /2001/2002	3rd air fan 2000	1995
No. 2 Unit				
Year of start-up			1989 (RB3)	
tBLS/d or MMlbBLS/d			3 MMlb/d	
% solids as fired			70	
Steam conditions psig/°F			600 psi / 750 °F	
Cascade / cyclone or evaporator concentrator ?			evap. + hi. sol. conc.	
Year combustion air system upgrade installed			1989	
Date of last major ESP upgrade			1989	
Year new ESP installed			1989	
LIME KILN				
Number of kilns	1	1	1	One
Emission control by ESP or Scubber?	ESP	Venturi Scrubber	scrubber	ESP
Year new ESP installed	N/A		--	1990
Nature and date of last changes that may have affected air discharges (up to 2005)	N/A	Slaker bowl replaced '05	added nozzles in 1994	2004 Chain upgrade
Natural gas fired? Y/N	none / Yes	Yes	Yes	Yes
NCG HANDING AND DISPOSAL				
CONCENTRATED NCG & STRIPPER OFF-GASES:				
PRIMARY INCINERATION IN				
Stand-alone incinerator	No			
Lime kiln	No			Stripper off gases
Recovey boiler	No			
Power boiler	Yes	Yes	Yes	Yes
SECONDARY INCINERATION IN				
Stand-alone incinerator	No			
Lime kiln	Yes	Yes	Yes	Yes
Recovey boiler	No			
Power boiler	No			Stripper off gases
DILUTE NCG:				
PRIMARY INCINERATION IN				
Stand-alone incinerator	No			
Recovey boiler	Yes	Yes		Yes
Power boiler	No		Yes	
SECONDARY DISPOSAL IN				
Recovey boiler	No			
Power boiler	Yes	Yes	Yes	
Vented	Emergency only			
location of venting discharge	Main stack (see note a)			
NCG STANDALONE INCINERATOR				
Emission control scrubber for SO2 removal?				
Fuels fired? (n. gas, oil, methanol)				
POWER BOILER				
Number in service	1	1	2	1
Number firing wood only or wood with fossil fuel	1	1	1	1
No. 1 Wood-fired power boiler			PB3	
Year of start-up	1993	1973	as PB3 in 1994 (RB1 1956)	1990
Grate type (travelling, pin-hole, BFB)		Pin hole	travelling	Travelling
Type emission control (ESP, multicyclone)	Multicione & ESP	Multicyclone & ESP	esp / multiclone	ESP
Date of last major ESP upgrade	N/A	1997	1992	none
Year new ESP installed	N/A	1997		1990
Is fossil co-firing Natural gas Y/N	Yes	Yes	Yes	Yes
No. 2 Wood-fired power boiler				
Year of start-up				
Grate type (travelling, pin-hole, BFB)				
Type emission control (ESP, multicyclone)				
Date of last major ESP upgrade				
Year new ESP installed				
Is fossil co-firing Natural gas Y/N				

NOTES: a - (re: Boyle DNCG Disposal) The main emergency vent discharges into the main stack. There are numerous other locations.

2.2 *Benchmarking of Air Emission Permit Limit Values*

2.2.1 *Tabulation of Alberta kraft mill permit limit values*

The permit limit values of the kraft mill air emission sources are presented in two ways. The first is Table 2.2 which expresses the limit values with the units used in the permits. The second table is required so that the Alberta kraft mill permit limit values can be expressed in units to allow comparison with standards and guidelines for selected major pulp and paper producing jurisdictions elsewhere.

Table 2.2 - Air Emission Permit Limit Values - Permit Units

	Recovery (a)				**Dissolver (a)**				**Kiln (a)**				**Power Boiler** (a)		
	NOx	PM	SOx	TRS	PM	PM	TRS	TRS	NOx	PM	SOx	TRS	NOx	PM	SOx
	ppm_{DV}	mg/SDm^3	ppm_{DV}	ppm_{DV}	kg/h	g/tBLS(f)	kg/h	g/tBLS(f)	ppm_{DV}	mg/SDm^3	ppm_{DV}	ppm_{DV}	ppm_{DV}	mg/SDm^3	ppm_{DV}
Boyle - ***Approval No. 111-02-00, effective Nov 30, 2006 through Oct 31, 2016***															
	-	100	-	5 (b)	11.75	95	1.75	14	-	150	-	8.(b)	-	100	-
GPrairie - ***Approval No. 113-02-00, effective Feb 28, 2007 through Jan 31, 2017***															
	-	100	-	5 (b)	-	-	-	-	-	150	-	8.(b)	-	100	-
Hinton - ***Approval No. 99-01-00, effective Feb 1, 1998 through Jan 31, 2008***															
(e)	-	150.(d)	250.(b)	6.5(c)	7.0	90	1.0	13	-	150	-	10.(c)	-	150.(d)	-
RB3	-	100	250.(b)	6.5(c)	-	-	-	-	-	-	-	-	-	-	-
Peace River - ***Approval No. 115-01-00, effective May 1, 1998 through April 30, 2008***															
	-	100	250.(b)	6.5(c)	5.0	50	1.5	16	-	150	-	10.(c)	-	150	-

Note: a - Reference oxygen content by volume of 8% for the recovery boiler, 10% for the kiln and 7% for the wood-fired power boiler with NOx as NO2, SOx as SO2, TRS as H2S

b - 12-h average

c - 4-h average

d - PM in the main stack which is the combined flow from RB2 and the wood-fired PB3

e - Applies to Recovery Boiler #2 (RB2) and the balance of the mill. The next row applies only to Recovery Boiler #3 (RB3).

f - Permit limit value is in kg/h. Approximate conversion to g/tBLS only.

Table 2.3 expresses the Alberta kraft mill permit limits in terms of mass emission concentration (mg/SDm^3), for all but the dissolver vent stack. By convention nowadays, the dissolver stack is expressed as a mass ratio of the recovery black liquor throughput.

Table 2.3 - Air Emission Permit Limit Values - Mass / Volume Concentration Units

	Recovery (a)				Dissolver (a)				Kiln (a)				Power Boiler (a)		
	NOx	PM	SOx	TRS	PM	PM	TRS	TRS	NOx	PM	SOx	TRS	NOx	PM	SOx
	mg/SDm^3	mg/SDm^3	mg/SDm^3	mg/SDm^3	kg/h	g/tBLS(f)	kg/h	g/tBLS(f)	mg/SDm^3	mg/SDm^3	mg/SDm^3	mg/SDm^3	mg/SDm^3	mg/SDm^3	mg/SDm^3
Boyle	-	100	-	7.0(b)	11.8	95	1.75	14	-	150	-	11.1(b)	-	100	-
GPrairie	-	100	-	7.0(b)	-	-	-	-	-	150	-	11.1(b)	-	100	-
Hinton (e)	-	150(d)	654(b)	9.0(b)	7.0	90	1.0	13	-	150	-	13.9(c)	-	150.(d)	-
Hinton - RB3	-	100	654(b)	9.0(b)	-	-	-	-	-	-	-	-	-	-	-
Peace R	-	100	654(b)	9.0(b)	5.0	50	1.5	16	-	150	-	13.9(c)	-	150	-

Note: a - Reference oxygen content by volume of 8% for the recovery boiler, 10% for the kiln and 7% for the wood-fired power boiler with NOx as NO2, SOx as SO2, TRS as H2S

b - 12-h average

c - 4-h average

d - PM in the main stack which is the combined flow from RB2 and the wood-fired PB3

e - Applies to Recovery Boiler #2 (RB2) and the balance of the mill. The next row applies only to Recovery Boiler #3 (RB3).

f - Permit limit value is in kg/h. Approximate conversion to g/tBLS only.

2.2.2 Tabulation of emission limits from Standards, Guidelines and Regulations

A good indicator of kraft pulp mill best current practice is to compare the limits from standards, guidelines and regulatory limits from demanding jurisdictions of major pulp and paper producing countries elsewhere. It should be recognized that in most jurisdictions, the standards, guidelines and regulatory limits are a starting point in the air emission permitting process, and an actual mill permit will generally be more restrictive depending on the projected ambient air quality of the area in the vicinity of the mill.

A compilation of these limits which would apply to newer mills or major rebuilds is presented in Table 2.4 which follows. This data is drawn from Section 5 - Overview of Key Regulations Elsewhere which reviews air emission regulations, standards and guidelines which with Appendix B – Air Emission Regulation and Management Measures, which presents the air emission regulations, standards and guidelines of Alberta, BC, Ontario, Quebec, the US, Sweden, Finland, the EU and the World Bank.

Table 2.4 - Emission Permit Limit Comparison for Selected Jurisdictions expressed in the units used in Alberta

Bleached kraft pulp mill source emission limit guidelines and permits comparison for selected jurisdictions for newer mills, or for major rebuilds representing Best Current Practice expressed at the Alberta standard conditons of 25°C, 101.325kPa and the reference oxygen conditions of the source indicated

Jurisdiction			British Columbia		Ontario		Quebec		USA		European Union (c)		Sweden (e)		Finland (d)			World Bank	
Basis			Draft Guidelines 1995		1990 Guidelines						IPPC-BAT								
Source	Pollutant	Units (a, b)	Value	Averaging time	Value	Averaging time	Value	Average, Frequency	Value	Averaging time	Annual Average	Daily Average	Annual Average	Monthly Average	Annual Average	Monthly Average	Daily Max	Annual Average	Value
Recovery Boiler corrected to 8% O2 by volume dry	PM	mg/SDm^3	49				100		33 (p)			22 - 37		40-66			40		
	TRS	mg as H_2S/SDm^3	9.8	1-h			7.0		7.0 (q)	12-h		6.6		7		8.4			
	NO_x	mg NO_2/SDm^3	236	1-h								60 - 89				159			
	SO_2	mg as S/SDm^3	128	24-h								3.7 - 7.4				79			
Dissolving Tank	PM	g/tBLS	60	1-h					60 (p)										
	TRS	g as H_2S/tBLS	8.4	12-h			16		16 (q)										
Lime Kiln corrected to 10% O2 by volume dry	PM	mg/SDm^3	79	1-h			127		23 (p)			19 - 31		38-157			40		
	TRS	mg as H_2S/SDm^3	11	1-h			11.8		11 (q)	12-h		9.4		33		14			
	NO_x	mg NO_2/SDm^3										63 - 126 (u)				336			
	SO_2	mg as S/SDm^3										1.6 - 9.4 (o)				134			
Power Boiler - Bark 7% O2 by volume dry	PM	mg/SDm^3	53 (l)		46 (m)		70 (i)		96 (l)			8.6 - 26		70-291					50.9 (s)
	NO_x	mg NO_2/SDm^3	258	1-h			(j)		229 (h)			161 - 268							662 (s)
	SO_2	mg as S/SDm^3	-	-			(k)		153 (r)			40 (v)							2,040 (s)
All sources (f)	PM	kg/ADt									0.2-0.5							0.5	
All sources (f,g)	Sulphur	kg S/ADt									0.3-0.6		0.4		0.4			0.6	
All sources (f)	TRS	kg S/ADt									0.1-0.2							0.2	
All sources (f)	NO_x	kg NO_x/ADt									1.0-1.5		1.3		1.5			2 (n)	

Notes:

a) In the Units column: All PM, TRS, NO_x and SO_2 values in the table are corrected to the O2 reference conditions that apply in Alberta. These are shown in the left hand column.
b) In the Units column: All emission limits converted to Alberta Standard (S) conditons of 25°C and 101.325kPa and Dry (D).
c) The EU has no specified % O2 reference level for the limits. Typical operating O2 levels are assumed of 3% O2 for the recovery boiler, 5% for the kiln and 7% for the power boiler.
d) Finland has an O2 reference condition of 6% by volume dry basis for all sources.
e) Sweden has no specified % O_2 reference level for the limits (with the exception of 10% CO_2 for the bark boiler taken to be 10% O2 by volume dry basis).
f) In the Basis column: Millwide includes all sources both major and minor but exclude power boilers.
g) In the Basis column: The contributions of both TRS and SO2 are included in millwide sulphur from all sources.
h) US: The NSPS NOx emission limits only apply to the oil, coal or gas component of the fuel input. Shown is the approximate limit value for 50%/50% heat input of wood and oil Oil NOx of 0.30lb/MBtu. The NOx of the wood fuel is not included for purposes of calculating the mass emission, but does dilute the concentration.
i) Quebec: For new units >10MW thermal heat input.
j) Quebec: No limit for units firing > 50% wood, < 50% fossil fuel.
k) Quebec: The sulphur limit on oil is 1.5% by weight.
l) BC: Greater than 20MW(72GJ/h) thermal input, otherwise 127mg/SDm3.
m) Ontario: For > 200t as fired wood fuel per day, otherwise 83mg/SDm3, also requires 1s residence time at temperature >1000°C.
n) World Bank: Value show is for softwood pulping. Guideline for hardwood pulp of 1.5 kg S/ADt.
o) The EU: For an oil fired kiln with no NCG firing. No guideline for gas fired kiln.
p) US: Maximum Achievable Control Technology (MACT) standard.
q) US: New Source Performancce Standard (NSPS).
r) US: The NSPS SO2 emission limits only apply to the oil, coal or gas component of the fuel input. Shown is the approximate limit value for 50%/50% heat input of wood and oil Oil SOx of 0.20lb/MBtu. The SOx of the wood fuel is not included for purposes of calculating the mass emission, but does dilute the concentration.
s) World Bank: For small (heat input > 3 and <50MW) solid fuel fired boilers, but can be up to 150mg/NDm3 if justified by envrionmental assessment. For larger units, the 1998 Thermal Power Guidelines are to be used. New Guidelines are currently in preparation but not available yet. See Appendix B.
t) US: This is the NSPS Standard since the much more demanding MACT standard of 10.8g/GJ (28mg/S_{2n}Dm3) has been withdrawn.
u) This is the value for oil firing; higher values are associated with gas firing.
v) This is sulphur from biofuel component of fuel fired. Other fuels have different emission factors.

A comparison of this and the previous table shows that the lowest value from the best current practice group (Table 2.4) are in most cases, a fraction of the Alberta mill levels (Table 2.3). This is hardly surprising given the advance of technology over the last two decades and noting that the most recently designed of the Alberta kraft pulp mills, the mill at Boyle is already 15 years old. Note that to facilitate comparison, the units for each table are the Alberta standard conditions of temperature, pressure and reference oxygen.

Ignoring averaging time, the most demanding (lowest) emission concentration from best current practice shown in Table 2.4 expressed as a percent of the most restrictive Alberta mill permit concentration, shows that:

- for the recovery boiler:
  - PM: the EU values are 20 - 33% of the lowest Alberta mill permit, and
  - TRS: the Quebec, US, Swedish values are comparable (100%) of the lowest Alberta mill permit;
- for the dissolver:
  - PM: the BC, US values are 120% of the lowest Alberta mill permit, and
  - TRS: the BC value is 65% of the lowest Alberta mill permit.
- for the kiln:
  - PM: the EU is 13-21% and the US 15% of the lowest Alberta mill permit, and
  - TRS: the BC, US values are 100% and Quebec 106% of the lowest Alberta mill permit
- for the wood-fired power boiler:
  - PM: the EU values are 9-27%, and the US 28% of the lowest Alberta mill permit.

It is noted that TRS emission concentrations for best current practice are not markedly lower than the Alberta kraft mills as was noted in the case of PM. An exception to this pattern is the case of the dissolver emission limits where the Alberta kraft mill permit limits are more stringent than best current practice emission limits. The reason for this is that the Alberta kraft mill permits are expressed in terms of kg/h, so that with production growth over the years, most of the mills are now processing more black liquor than originally designed for, which has the effect of reducing the mass ratio of the emission (kg/tBLS).

For further perspective on the Alberta kraft mill permits, the permit limit values for mills of a similar age for selected Canadian, US, and European mills for the 1990-95 period are presented in the following figures. The most demanding of best current practice emission concentrations of Table 2.4 are included for comparison. The permit limit values for mills of a similar age are taken from a paper published in 2003[1], and include data from 20 kraft pulp mill permits. The gap between the older data and the best current practice today highlights the progress made since the early 1990s. For the purpose of showing this gap, it is appropriate that the older permit data not be updated, though it is recognised that in the case of some mills, the permit data may be out of date if the mill has been upgraded and therefore re-permitted since the data was collected. Also shown for reference is an older permit limit value representative of limits in the mid-1970s to mid-1980s.

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[1] D. Bruce, T. van der Vooren: *Trends in air emission limits for world class mills*, Pulp and Paper Canada, T190, 104:7 (2003)

In the following Figures 2.1 – 2.4, the lowest permit limit value from the Alberta kraft mills and the lowest emission concentration from the best current practice guidelines of Table 2.4 are presented. In the case of Best Available Techniques as defined by the EU's Integrated Pollution Prevention and Control (IPPC-BAT) where a range of values is identified, the average of the range is shown.

2.2.3 Benchmarking Alberta kraft mill permits

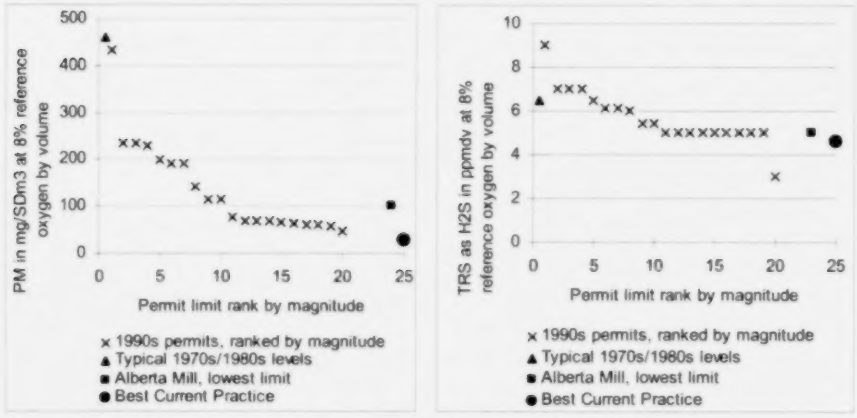
PM in mg/SDm3 at 8% reference oxygen by volume
Permit limit rank by magnitude
TRS as H2S in ppmdv at 8% reference oxygen by volume
Permit limit rank by magnitude
x 1990s permits, ranked by magnitude
▲ Typical 1970s/1980s levels
■ Alberta Mill, lowest limit
● Best Current Practice

Figure 2.1 - Recovery boiler permit limit values for PM and TRS

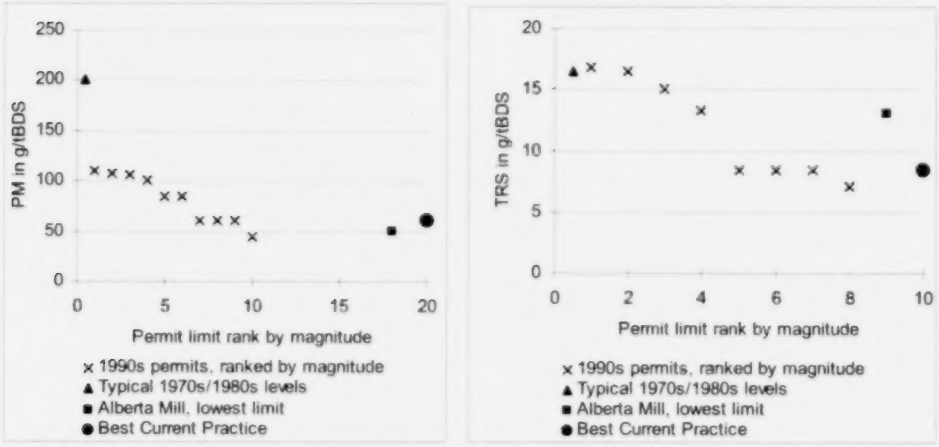
PM in g/tBDS
Permit limit rank by magnitude
TRS in g/tBDS
Permit limit rank by magnitude
x 1990s permits, ranked by magnitude
▲ Typical 1970s/1980s levels
■ Alberta Mill, lowest limit
● Best Current Practice

Figure 2.2 - Smelt dissolver permit limit values for PM and TRS

For the recovery boiler and smelt dissolver emissions, as one would expect, the limit values of the Alberta kraft mill permits are higher than best current practice. The only anomaly is the low value of smelt dissolver PM in relation to best current practice. This is due to the permit limit being expressed as a kg/h rate for the Alberta mills, which with production creeping over the

years, results in the emission level decreasing when expressed in terms of g/tBLS, since the black liquor throughput for each mill in 2005 has been used.

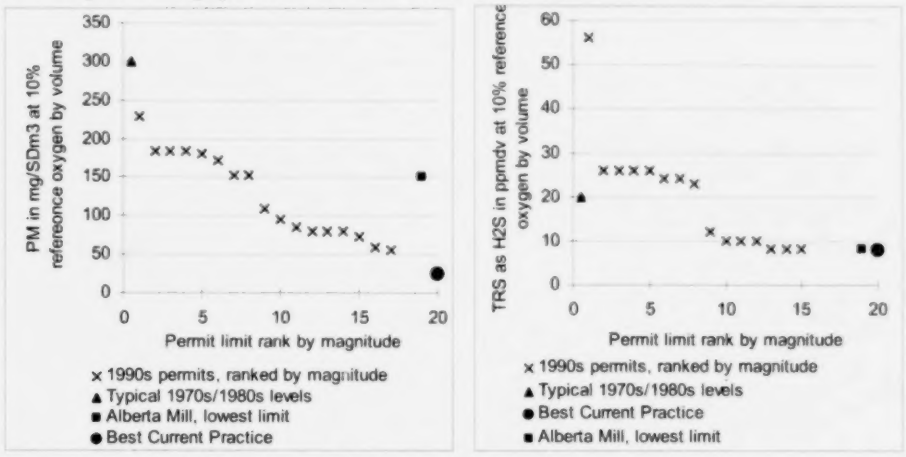

Figure 2.3 - Lime kiln permit limit values for PM and TRS

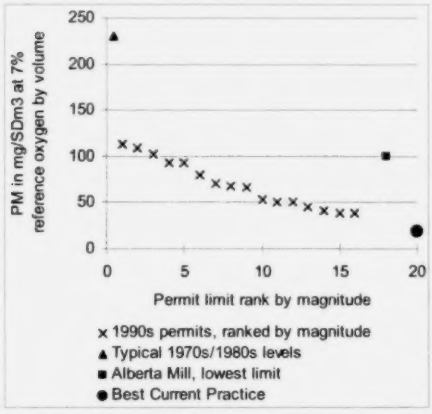

Figure 2.4 - Wood-fired power boiler permit limit values for PM

As with the recovery boiler, the best current practice PM limit values of the lime kiln and the power boiler are lower than the limits of the Alberta kraft mill permits, but by a wider margin. This reflects the concern over fine PM (PM_{10}) and very fine particulate matter ($PM_{2.5}$) which resulted in the introduction of much tighter limits on PM in the US and elsewhere starting in the late 90s. This concern occurred well after the mill at Boyle, the most recent of the Alberta mills, was designed and built.

2.3 Benchmarking Air Emission Discharges

Major sources of emissions are compared by benchmarking the concentration of contaminants in the next subsection. The subsection after that presents total mill wide emissions of contaminants

from the kraft pulp mill benchmarked by contaminant emitted per tonne production as is the industry norm,

2.3.1 Source emission benchmarking - 2005

Emission concentration sampling data submitted to Alberta Environment from the main kraft pulp mill sources was assembled for the four Alberta kraft mills, and a number of Canadian and US kraft pulp mills.

While Finland and Sweden publish kraft mill emission data, they only provide emissions for major sources expressed in kg emitted per year, and per tonne production. No data is provided on a concentrations basis. Also, the Finnish mill source data provided is only for the pulp mill as a whole, which does not provide the needed breakdown by source which this subsection presents. The Swedish data is by major source for NOx and sulphur, but the latter combines TRS and SO_2, each of which is required. PM is provided on a mill wide basis. The result is that only NOx for the Swedish data could, by means of factors, provide approximate estimates of NOx concentration. However, NOx control is inherent in combustion device design and not a matter of add-on controls. Thus national emission levels are considered to be of lesser interest than, say, PM. Accordingly, no Swedish data is presented in this subsection. Mill wide benchmarking of the Alberta kraft mills against Finnish and Swedish mill sources is presented on a mill wide basis in the next subsection 2.3.2.

All the kraft mill emission data is for the year 2005. With the exception of discharges from the smelt dissolver, all Alberta kraft mill data was available in concentration form using the units and gas conditions of the permits. These gas conditions are the Standard (S) conditions for Alberta: 25°C and 101.325kPa, Dry (D), and the percent O_2 by volume reference levels of 8% for the recovery boiler, 10% for the kiln and 7% for the power boiler and expressed on a dry basis. For the dissolver, the sampling results were converted to g/tBLS, the industry standard for this source.

For all but PM, which has to be expressed in mg/SDm^3, concentrations are presented in volume ratio terms as parts per million dry volume (ppm_{DV}), the units of the Alberta kraft mill permits. This differs from the general European practice which expresses concentration as a mass per unit volume, i.e., mg/NDm^3, where N stands for Normal gas conditions of 0°C and 101.325kPa.

The Alberta kraft mill emissions for 2005 expressed as concentrations are presented in Table 2.5. As the Hinton mill has two recovery boilers, two rows are used to present the Hinton data.

Table 2.5 - Alberta Kraft Mill Air Emissions Expressed In Concentration - 2005

	Recovery (a)				Dissolver (a)				Kiln (a)				Power Boiler (a)		
	NOx	PM	SOx	TRS	NOx	PM	SOx	TRS	NOx	PM	SOx	TRS	NOx	PM	SOx
	ppm_{DV}	mg/SDm^3	ppm_{DV}	ppm_{DV}	g/tBLS	g/tBLS	g/tBLS	g/tBLS	ppm_{DV}	mg/SDm^3	ppm_{DV}	ppm_{DV}	ppm_{DV}	mg/SDm^3	ppm_{DV}
Boyle	72.0	48.0	6.1	0.2	-	10.2	18.3	3.4	61.5	45.0	15.7	0.7	-	130	-
GPrairie	54.0	54.9	2.0	1.8	-	0.0	-	1.8	182	75.5	-	3.6	127	46	273
Hinton - (b)	76.8	132	55.4	0.4	-	208	-	2.0	150	62.0	-	0.2	71.7	123	116
Hinton - RB3	54.3	60.5	34.8	0.8	-	98	-	2.3	-	-	-	-	-	-	-
Peace R	77.8	54.7	6.7	0.2	-	141	17.1	2.2	79.6	12.7	78.1	-	140	33.5	-

Note: a - O_2 reference level of 8% for the recovery boiler, 10% for the kiln and 7% for the power boiler with NOx as NO2, SOx as SO2, TRS as H2S

b - Applies to Recovery Boiler #2 (RB2) and the balance of the mill. The next row applies only to Recovery Boiler #3 (RB3).

The Canadian and US mill data for the pulp mill is taken from recent National Council of the Paper Industry for Air and Stream Improvement (NCASI) reports based on mill data collected in the 1995 - 2005 time period. The NCASI reports used are:

- Special Report 05-03[2], which provides Canadian mill data on speciated VOC measurements of numerous sources as part of the FPAC 20 mill study in addition to providing emission data on CO, NO_x, PM, SO_2, TRS and VOC of the main sources;
- Technical Bulletin No. 884[3] providing data on CO, NO_x, PM, SO_2, TRS and VOC emissions for Canadian and US kraft pulp mills; and
- Technical Bulletin No. 849[4] providing data on TRS for Canadian and US kraft pulp mills.

In discussion with NCASI, it appears that there was no systematic attempt to select mills representative of the range of types or age of emission control devices of the main mill sources. This applies for both the Canada and the US mill data. Rather, the data in these three reports reflects the data that was made available by the industry to NCASI and FPAC in response to questionnaires. Accordingly, it should not be assumed that the results are representative of the performance of the stock of mills in the two countries.

In most cases the NCASI emissions data is presented in lb/ADT or lb/TBLS, and the Swedish mill data in kg/ADt. To be suitable for comparison with the Alberta mills, the data was converted to a gas concentration for all but PM and the dissolver data. With the exception of the Grand Prairie mill which submitted no data in concentration form, the Alberta mills data was available both in kg/h and as a concentration.

The source of the data for the power boilers is described further on.

It is now accepted practice to express the smelt dissolver emissions in terms of g/tBLS or kg/tBLS. The reason for this approach when comparing dissolver emissions is due to the inconsistent data that results if emissions are expressed on a concentration basis. This is due to the widely varying amounts of air in-leakage from recovery to recovery which affects the vent stack flow rate independently of the mass emission rate. As the Alberta mill dissolver data was

[2] NCASI - A Comprehensive Comparison Of Canadian And US Pulp And Paper Mill Air Emission Data, Special Report 05-03, November 2005

[3] Compilation of Criteria Air Pollutant Emissions Data For Sources At Pulp And Paper Mills Including Boilers, Technical Bulletin No. 884, August 2004.

[4] Compilation Of Speciated Reduced Sulfur Compound And Total Reduced Sulfur Emissions Data For Kraft Mill Sources, Technical Bulletin No. 849, August 2002

not expressed in terms of g/tBLS, this was estimated using a black liquor flow rate of 1.6 tBLS/ADt since neither the black liquor flow rate nor the vent gas flow rate was available. These and other conversion factors are presented in Table 2.6.

Table 2.6 – Approximate Conversion Factors Used

Parameter	Factor	Units
Black liquor solids per ADt production	1.600	tBLS/ADt
Tonnes CaO per ADt production	0.275	tCaO/ADt
Recovery flue gas per tBLS	5700	SDm^3/tBLS - 8% O2
Recovery flue gas per ADt production	9100	SDm^3/ADt - 8% O2
Kiln flue gas per tCaO	1175	SDm^3/tCaO - 10% O2
Kiln flue gas per ADt production	4200	SDm^3/ADt - 10% O2
Dissolver flue gas per tBLS	510	SDm^3/tBLS
Dissolver flue gas per ADt production	830	SDm^3/ADt

These factors are adapted from those presented on page 2 of the above mentioned NCASI Technical Bulletin 884 *Compilation of Criteria Air Pollutant Emissions Data for Sources at Pulp and Paper Mills including Boilers*, adjusted for the Alberta standard temperature of 25°C since the NCASI standard is 20°C.

It is noted that no factor is provided for power boiler flue gas flow per ADt. This is because power boiler size and their emissions do not relate to pulp mill production rate. For instance, modern kraft pulp mills may have no power boiler, and in older mills, steam is often generated for power generation beyond the strict needs of the kraft pulp mill such as for power generation and power export.

These factors provide approximate estimates only as the actual factors are mill specific and depend on the chemical analyses of the black liquor, wood waste and fossil fuels fired, species pulped and pulp to chip yield.

In the subsections that follow, each of the four groups of data, the Alberta kraft mills, the Canadian mills, the US mills, and the Swedish kraft pulp mills are ranked by emission magnitude from lowest to highest. The rank of a particular mill does not necessarily remain the same for each emission being considered and most likely will change. For the Alberta mills, the data points are labeled.

2.3.1.1 Benchmarking Discharges - Recovery Boiler

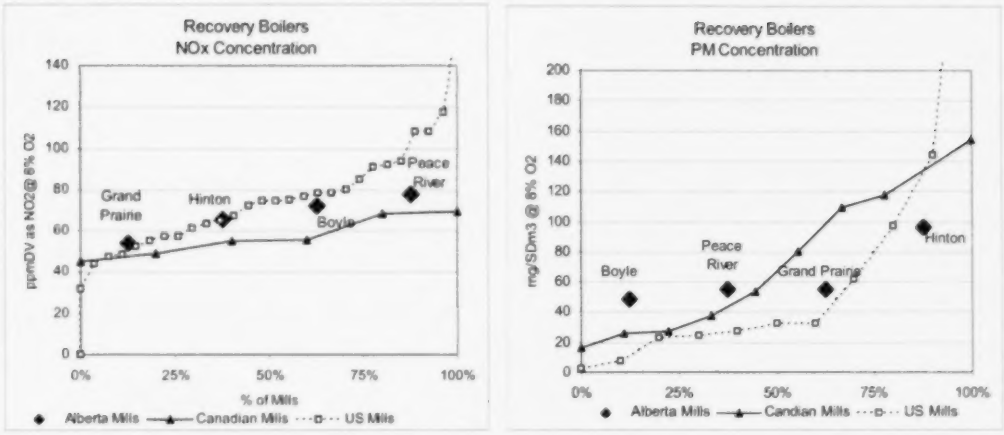

Figure 2.5 - Recovery NOx and PM

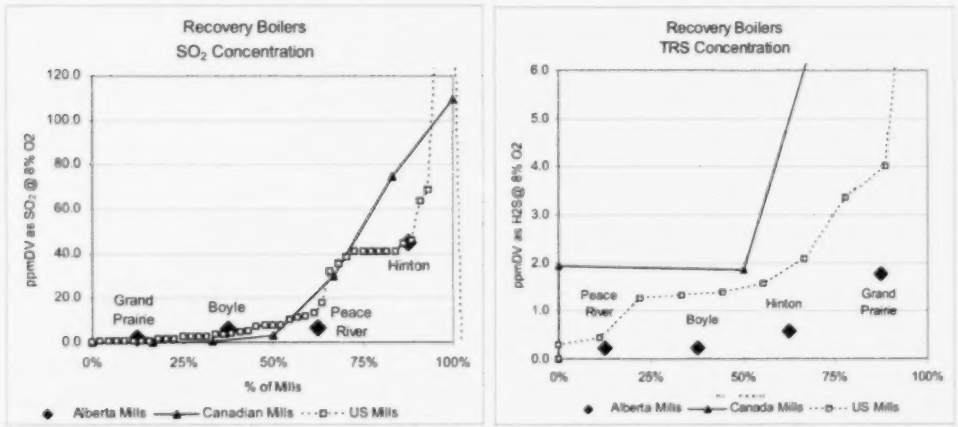

Figure 2.6 - Recovery SO_2 and TRS

As the Hinton mill has two recovery boilers, the average of the two recovery boiler data is used.

The chart for NOx show the median values of the Alberta recoveries, though somewhat higher than the Canadian recoveries, approximate those of the US recoveries.

Median values of PM for the Alberta recoveries are in line with the median of the Canadian recoveries but both are nearly double the median value of the US recoveries.
SO_2 shows results generally in line with US and Canadian recoveries, and, although Hinton has higher emissions, it is at a level of the bottom quartile of the Canadian recoveries.

TRS for the Alberta recoveries are significantly lower than the Canadian and US recoveries, probably due to the Alberta recovery boilers being generally more recently installed than the Canadian and US recoveries of which some at least are likely to be overloaded.

2.3.1.2 Benchmarking discharges - Smelt Dissolver

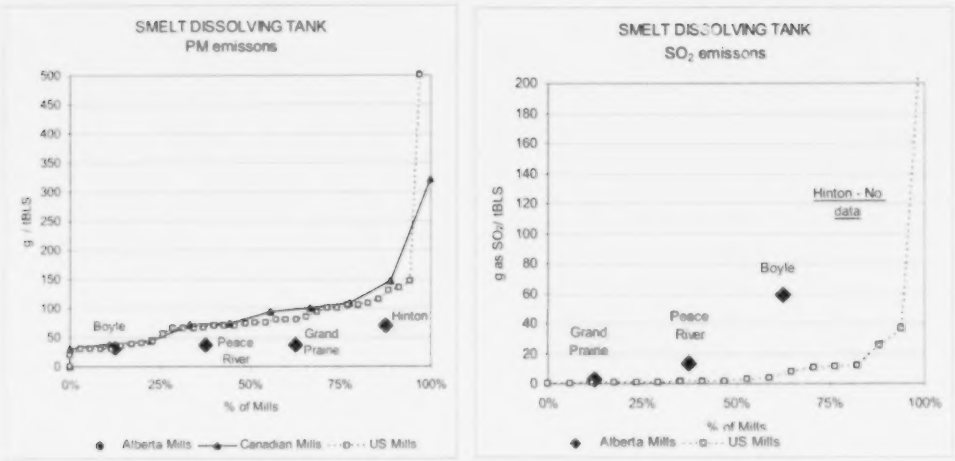

Figure 2.7 - Smelt Dissolver - PM and SO_2

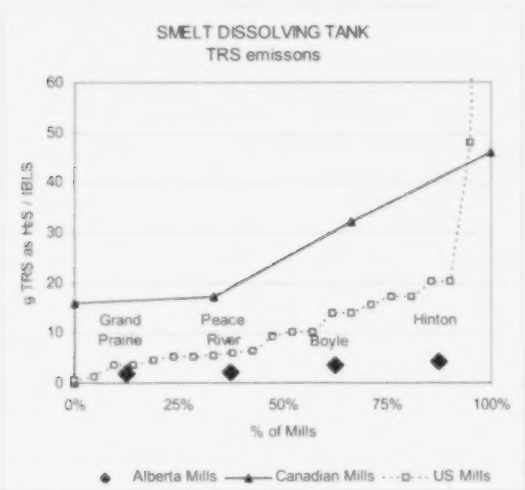

Figure 2.8 - Smelt Dissolver TRS

The charts for PM and TRS show that emission control of the Alberta dissolvers are performing better than the median of their Canadian and US counterparts and in line with those best performing. The exception is SO_2 emissions, which are significantly higher than the levels for this source in Canadian and US mills.

2.3.1.3 Benchmarking discharges - Lime Kiln

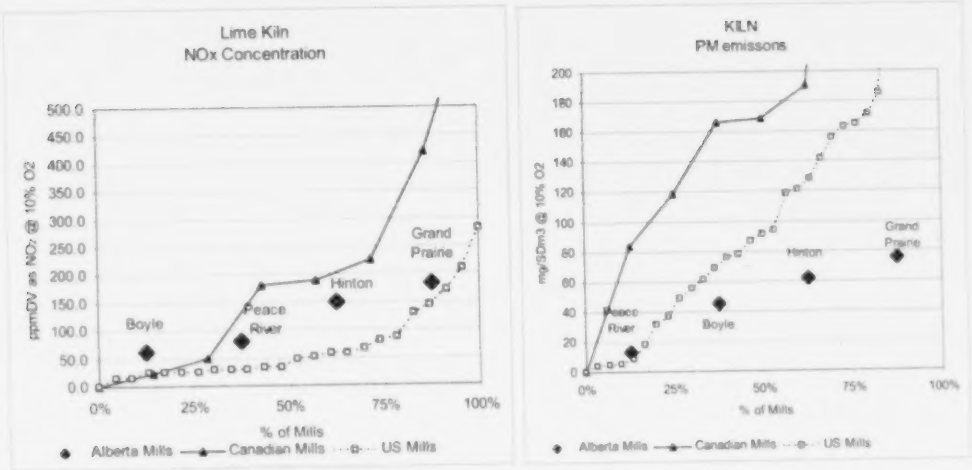

Figure 2.9 - Lime Kiln NOx and PM

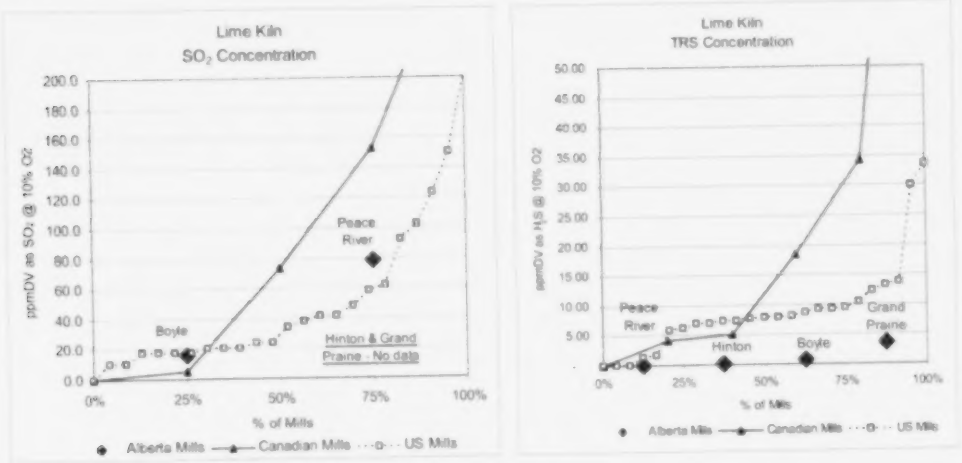

Figure 2.10 - Lime Kiln SO_2 and TRS

The chart for kiln NOx emissions shows the Alberta mills to be in between the those of the US and the Canadian mills. PM data for the Alberta mills are well below the median value of the US and the Canadian mills for this source.

SO_2 data is available for only two mills. Both show values less than the median of Canadian mills, but higher than the US mills for this source.

TRS from the kiln for the Alberta mills are significantly lower than the other Canadian and US mills.

2.3.1.4 Benchmarking discharges - Wood-fired Power Boiler

The data for Canadian mills is taken from the NCASI Special Report 05-03 and includes only those power boilers firing wood only or wood in combination with other fossil fuels. The data for oil only and coal only fired boilers were excluded. In total there were 23 power boilers firing wood. Notes with the data indicate that out of the total, 6 were equipped with mechanical collectors (multi-cyclones), and the balance had ESPs, wet scrubbers, ESPs with wet scrubbers, or wet electrostatic precipitators. The four sets of wet electrostatic precipitator data were all taken from one boiler at a West Coast mill.

For the US power boiler data, NCASI generously made available a spreadsheet of US EPA data used for establishing emission factors for the US EPA's AP-42[5] for "wood waste combustion" which comprises wood-fired boilers and heaters. This large data set includes all available wood-fired units in pulp and paper, sawmills and other wood-related industries such as furniture manufacturing plants. This data is believed to contain some data that is a decade or more old. Data consists of 204 PM records, 34 NO_x records and 23 SO_2 records.

NCASI were not able to confirm that the results are representative of the stock of furnace types and emission control technologies either in the Canadian mills or in the US establishments with wood waste fired boilers and heaters. Furthermore, it is known that the data sets are not complete. So drawing industry-wide conclusions from what is incomplete data on the entire US stock of wood-fired boilers is inappropriate.

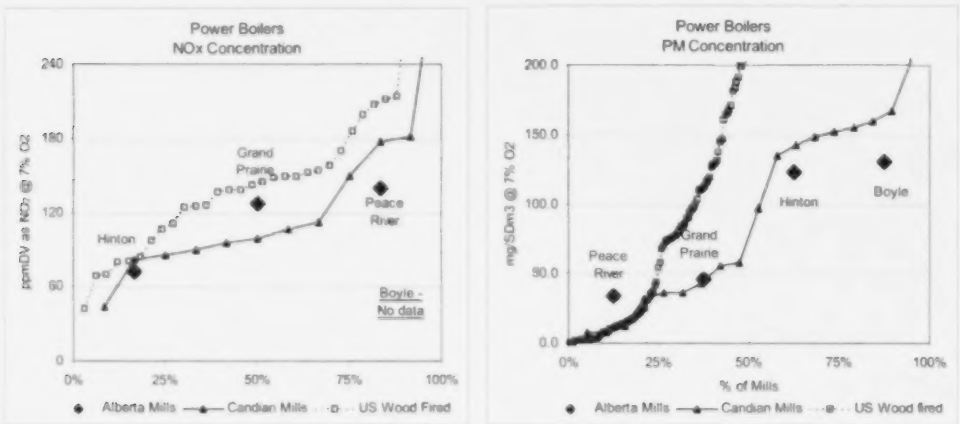

Figure 2.11 - Wood-fired Power Boiler - NOx and PM

[5] http://www.epa.gov/ttn/chief/ap42/ch01/index.html

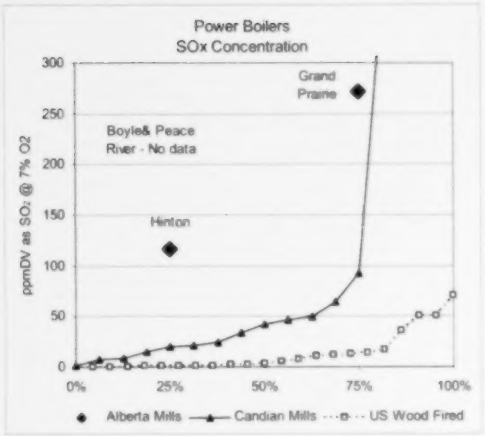

Figure 2.12 - Wood-fired Power Boiler - SO_2

The chart for NO_x show the emission values from power boilers in Alberta to be generally in line with the emissions from the Canadian and the US mills. The very large number of PM data for the US power boilers shows a high median value of above 200mg/SDm^3 (off the graph), which is a poor basis for comparison, since the data show that many US power boilers and heaters have very low PM emissions of below 50mg/SDm^3.

SO_2 data is available for only two of the Alberta kraft mills, and both values are much greater than the data from other Canadian and US power boilers.

2.3.1.5 Source Emissions of Some Recent World Class Mills

The emission concentration values presented in Table 2.7 compare best current practice for new mills from the perspective of:

- the European Union - Best Available Techniques[6];
- the USA - Maximum Achievable Control Technology (MACT) limits[7]; and
- the Tasmanian Guidelines[8].

In addition some recent anticipated emission levels for two kraft mill projects in Uruguay. The Uruguayan projects are the Botnia[9] mill which has just started up in November 2007 and the proposed Ence-CBM[10] mill, both greenfield installations. Note that the Ence project data is for

[6] http://eippcb.jrc.es/pages/FActivities.htm

[7] MACT for recovery boilers and lime kilns: http://www.epa.gov/ttnatw01/pulp/pulppg.html; MACT for industrial boilers has met a legal challenge and has been withdrawn: http://www.epa.gov/ttn/atw/boiler/boilerpg.html

[8] http://www.rpdc.tas.gov.au/bekm/final_report

[9] MIGA-Environmental Assessment, report E1109, World Bank for Botnia mill Uruguay: http://www-wds.worldbank.org/external/default/main?pagePK=64193027&piPK=64187937&theSitePK=523679&menuPK=64187510&searchMenuPK=64187283&theSitePK=523679&entityID=000012009_20050317135650&searchMenuPK=64187283&theSitePK=523679

[10] Ence-CMB mill described in the Cumulative Impact Study – Uruguay Pulp Mills, EcoMetrix Incorporated, Sept 2006.

the mill as originally proposed; the revised larger mill does not yet have publicly submitted environmental data.

Table 2.7 - Best Current Practice - Source Concentrations Expressed in the Units[a] And Reference Oxygen Content Used by Alberta Envrionment

		(a) Units (f)	Botnia (i)	Ence-CMB	Tasmanian	EU IPPC-P & P	US
			Uruguay	Proposed Uruguay	Guidelines	BAT - Max	EPA
Recovery Boiler corrected to 8% O_2 by volume dry	PM	mg/SDm^3	40	33(b)	33	37	33.4
	NOx	ppmDV	74	76(b)	mill wide (h)	47	-
	SO_2	ppmDV	2.5	15.8(b)	mill wide (g)	5.7	-
	TRS	ppmDV	5.1	2.4(b)	3.3(j)	≈ 4.8	5.0
Lime Kiln corrected to 10% O_2 by volume dry	PM	mg/SDm^3	39	-	22	31	22.6
	NOx	ppmDV	60	-	mill wide (h)	67	-
	SO_2	ppmDV	35	-	mill wide (g)	72 (L)	-
	TRS	ppmDV	8.6	-	6.4(k)	6.8	8.0
Power Boiler - Bark corrected to 7% O_2 by volume dry	PM	mg/SDm^3	-	26(d)	29.6	26	28(c)
	NOx	ppmDV	-	-	≈100(e)	143	-
	SOx	ppmDV	-	-	-	15	-

Notes:

a All PM, TRS, NOx and SO_2 values in the table are corrected to the O_2 reference oxygen conditions in Alberta, which are indicated in the left hand column. NOx as NO_2, SO_2 as SO_2, TRS as H_2S.

b – Cumulative Impact Study, Uruguay Pulp Mills, Sept 2006, Appendix 8 - A8-36 (p112/205).

c - Proposed but withdrawn MACT limit for new boilers is 10.8g/GJ (0.025lb/MBtu) wood fuel heat input. Estimated using 2.48 x 10^{-7} $DS_{20}m^3/J$ at 0% excess O_2 (US-EPA 'F' factor for wood).

d - Cumulative Impact Study, Uruguay Pulp Mills, Sept 2006, Appendix 8 - A5-4 (p35/205).

e - Limit is 80g/GJ fuel input. Estimated using 2.48 x 10^{-7} $DS_{20}m^3/J$ at 0% excess O_2 (US-EPA 'F' factor for wood).

f - NOx as NO_2, SOx as SO_2, TRS as H_2S.

g - Included in mill-wide sulphur total excluding the power boiler..

h - Included in mill-wide NOx total excluding the power boiler.

i - 90% of the time. Souce: MIGA - EIA dated 2005-02-01, pg 138 of 618.

j - More than 99% of the time, meaning the limit may only be exceeded for up to 7-h per month.

k - More than 95% of the time, meaning the limit may only be exceeded for up to 36-h per month.

L - Value for oil fired kiln with NCG burning is 150 - 300mg SO2/NDm3 at 5% O2 level (47 - 94ppmDV); no BAT value provided for gas fired kiln.

2.3.2 Mill wide emission benchmarking - 2005 Data

2.3.2.1 Mill Wide Emissions of Albertan, Canadian, Swedish and Finnish Mills

http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/SFILE/Uruguay_CIS_AnnexC_Oct2006.pdf

This subsection presents bleached kraft pulp mill wide emissions on a per tonne pulp production basis. Data for the 4 Alberta mills is compared with 21 non-integrated Canadian mills and similar mills in Finland and Sweden where suitable data was found.

The Canadian mill data was obtained from Environment Canada. The Finnish and Swedish data were obtained from websites[11,12]. No comparable pulp mill wide data on US kraft mills was found, though one source[13] provided minimum, median and maximum values for the principle sources based on results from a survey of mills. However, it would not be correct to add these statistical metrics of the main sources as estimates of mill wide values, as the minimum, median and maximum values are most likely from different mill sites.

For proper mill benchmark comparison, power boilers should not be included in the mill wide total as their emissions are not proportional to pulp mill production rate. New kraft pulp mills do not need a power boiler to achieve self-sufficiency in process steam and power, while in older kraft pulp mills, power boiler steam raised is often used in pulp mill processes and for power generation and the amount beyond the strict needs of the kraft pulp mill such as required for power export.

The usual approach for benchmarking power boiler emissions of NOx, PM and SOx is to base it on heat input (g/GJ). In the case of the Alberta mills, the required heat inputs of the different fuels were not requested by the regulatory authorities and so the emissions could not be expressed on a heat input basis. As TRS emissions are virtually all from the pulping area, the recovery boiler and the kiln, the power boiler contribution is irrelevant.

For the Albertan, Canadian, and Swedish mills, the emission data is the sum of all the major sources at the site including the power boilers. For the Canadian mills, Environment Canada cannot provide a breakdown giving the contribution of the power boilers. The contribution of the power boilers from only some, but not all of the Alberta mills is available. The Finnish data separates out the power boilers allowing the mill wide emissions to be presented with and without the power boiler, but the Swedish data does not provide a breakdown giving the PM contribution from the power boiler.

Accordingly, the emissions from the power boilers are included, contrary to convention. To make the data from these sources as comparable as possible, only non-integrated market kraft pulp mills were selected for comparison to eliminate power boiler emissions associated with steam used in a paper mill, or the like. However, the data may still include inappropriate power boiler emissions such as those associated with steam raised for power generation for export which may be in part, as in some Norscan mills, condensing power generation. The mill wide data are presented in Figures 2.13, 2.14, and 2.15 presented at the end of the next subsection.

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[11] EPER: http://www.eper.cec.eu.int/eper/Finnish Forest Industries Federation (FFIF): www.forestindustries.fi FFIF contacts: http://www.forestindustries.fi/esittely/yhteystiedot.htm
Environmental statistics form paper and pulp industry 2006 (Metsäteollisuuden ympäristötilastot vuodelta 2006): http://www.metsateollisuus.fi/Infokortit/ymparistotilastot2006/Documents/Mets%C3%A4teollisuuden%20ymparistotilastot%202006.pdf

[12] http://miljodatabas.skogsindustrierna.org/si/main/reportselect.aspx?l1=report

[13] NCASI - A Comprehensive Comparison Of Canadian And US Pulp And Paper Mill Air Emission Data, Special Report 05-03, November 2005

2.3.2.2 Mill Wide Emissions of Some Recent World Class Mills

Best Current Practice air emissions on a mill wide basis are presented in Table 2.8, using the same mills and guidelines discussed in Section 2.3.1.5, namely, IPPC-BAT, the Tasmanian Guidelines and the two new kraft mill projects in Uruguay. It is noted that US MACT does not have a guideline for mill wide emissions. This data is summarized in the Botnia environmental review document[14].

Thus Table 2.8 provides the basis for a benchmark of what is expected to be achieved today in new world class mills. Note that the mill wide emissions exclude the power boiler, which in modern mills is not required for pulp production.

Table 2.8 - Comparison of Best Current Practice - Mill wide Emissions [a]

	Units	Botnia	Ence-CMB	Tasmanian Guidelines	European Commission
		Uruguay	Uruguay		BAT
PM	kg/ADt	0.3	0.34 (b)	-	0.2-0.5
NO_x	kg as 'NOx' /ADt	1.35	1.30 (b)	1.3	1.0-1.5
SO_2	kg as 'SO_2' /ADt	0.6	0.46	-	0.4-0.8
Sulphur (c)	kg as 'S' /ADt	0.35	0.26 (b)	0.4	0.3-0.6
TRS	kg as 'H2S' /ADt	0.053	0.032	-	0.1-0.2

Notes:
a - The mill-wide emissions exclude the power boiler.
b - Annual average
c - Includes TRS and SO2 both expressed as sulphur

For each emission type, the lowest value in Table 2.8 is presented as a wide horizontal line in Figures 2.13, 2.14, and 2.15 which follow, along with data on Canadian, Swedish and Finnish mills described in Subsection 2.3.2.1.

[14] Appendix A8 - Page A5.4 of the Cumulative Impact Study for two recent Uruguayan pulp mills: Cumulative Impact Study – Uruguay Pulp Mills, EcoMetrix Incorporated, Sept 2006. http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/$FILE/Uruguay_CIS_AnnexC_Oct2006.pdf

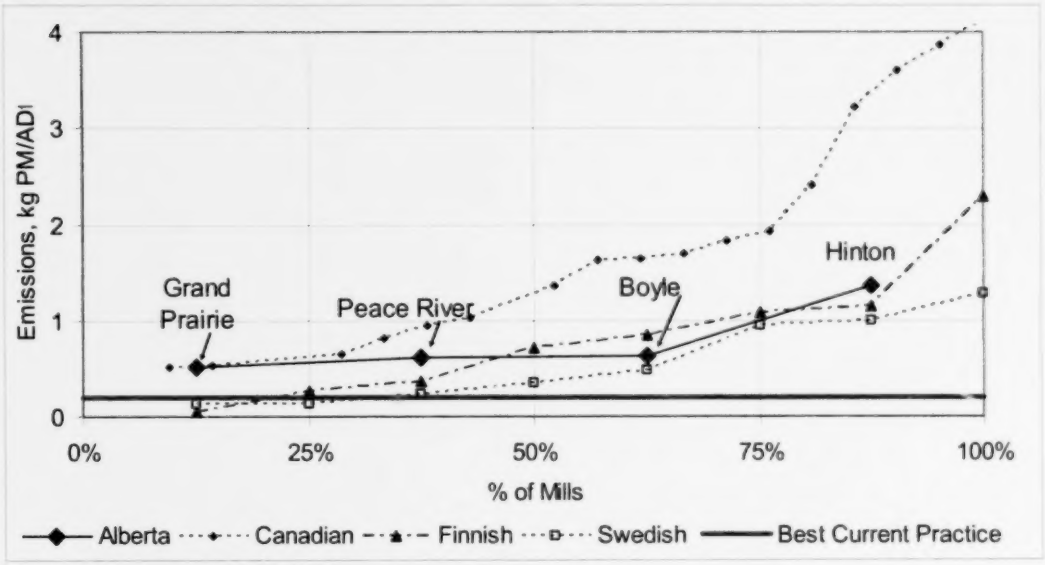

Figure 2.13 - Mill wide Benchmarking - PM

This chart shows that the mill wide PM emissions from the three best performing and most modern Alberta mills are the lowest in Canada and are comparable with the median Finnish mill, though much higher than the median Swedish mill. It is noted as well that several Swedish and Finnish mills are at or exceed best current practice emissions.

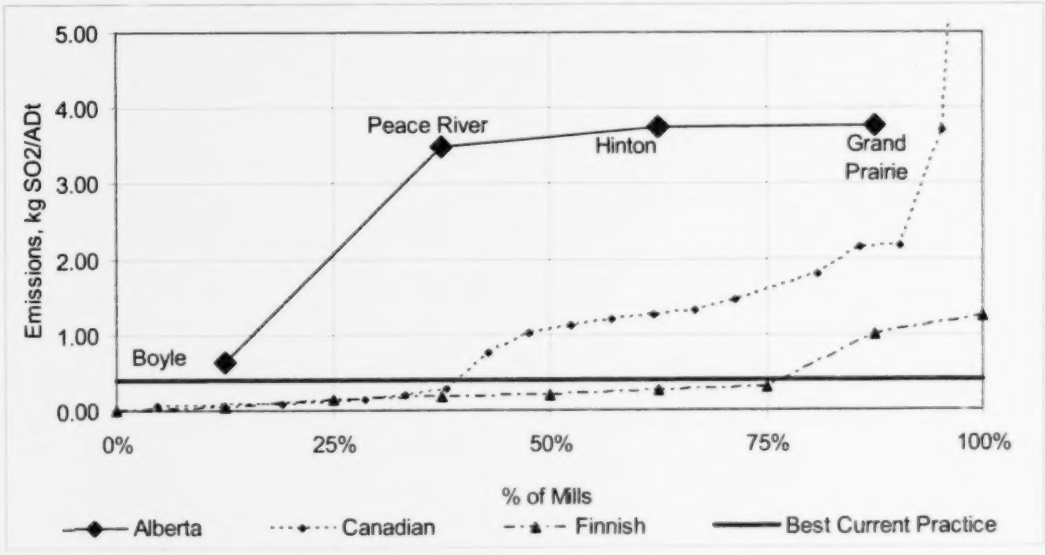

Figure 2.14 - Mill wide Benchmarking – SO_2

This chart shows that the mill wide SO_2 emissions from the Alberta mills with the exception of the mill at Boyle, are exceptionally high compared with other Canadian, Swedish and Finnish mills. The reasons for this anomaly have not been determined. It is possible that for the Canadian mills, SO_2 emissions from certain sources such as recovery boilers or lime kilns are not reported and therefore not included in the totals.

There is no separate SO_2 data available for Swedish mills as this emission is combined with TRS and presented as a single emission of sulphur.

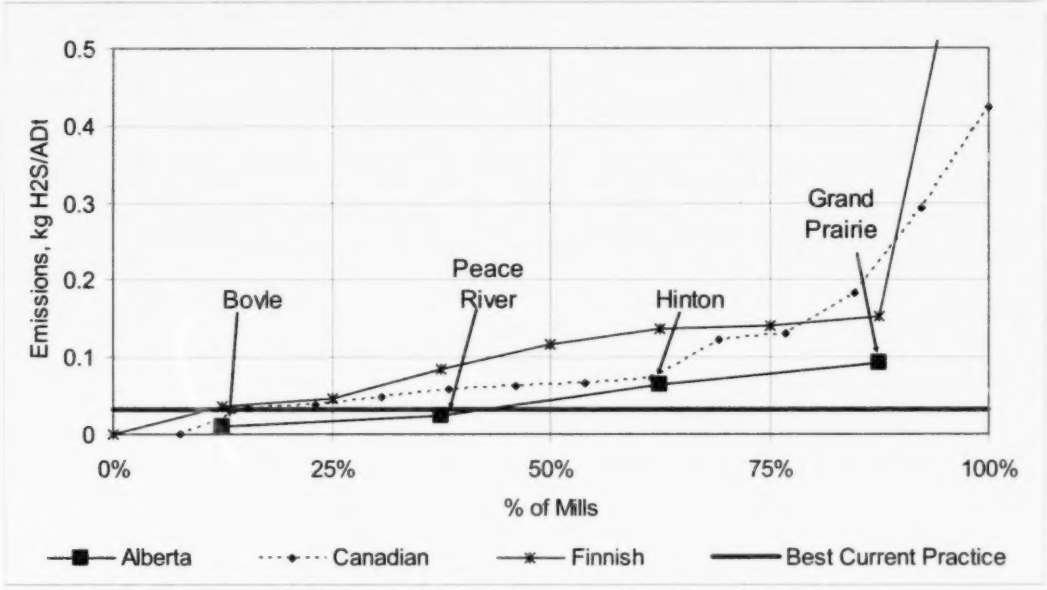

Figure 2.15 - Mill wide Benchmarking - TRS

There is no separate TRS data available for Swedish mills as this emission is combined with SO_2 and presented as a single emission of sulphur. This is unfortunate since the nuisance to humans associated with a given mass rate emission of TRS is several orders of magnitude greater than that of SO_2.

3.0 TECHNOLOGY USED IN NEW WORLD CLASS KRAFT PULP MILL DESIGNS

3.1 Terminology

In South America and Australia a number of new world class mills are being designed or have recently started up. The term world class is usually taken to mean a mill that has not only the very largest production capacity production lines, but also one that the uses the latest proven process technology, and is of advanced design that is generally consistent with meeting the most stringent emission standards anywhere in the world.

In the case of the Botnia greenfield kraft pulp mill in Uruguay, the project has received close environmental scrutiny because of the involvement of leading international lending institutions that demand projects be environmentally responsible. In the case of the Bell Bay mill recently approved for Tasmania (Australia), the regional government put in place demanding guidelines well in advance of any formal development proposal by the proponent.

This section will describe the process technology and design of world class mills as they relate to minimizing air emission discharges. This section assumes the reader is familiar with pulp and paper processes and air emission control technologies; for further detail, the reader is referred to Appendix C - Mill Processes, their Air Emissions and Controls.

One term covering best current practice environmental design is Accepted Modern Technology (AMT) as used by the Tasmanian authorities. Their guidelines[15] are based on a review[16] undertaken in 2003/4 by a consortium headed by Beca-AMEC. The study reviewed state-of-the-art kraft pulp mill technologies and management practices, aimed at minimizing the environmental impact of pollutants released from BEKP mills. AMT is defined as:

> *'technology which has a demonstrated capacity to achieve the desired emission concentration in a cost-effective manner, takes account of cost-effective engineering and scientific developments, and pursues opportunities for waste minimisation.'*

The meaning of AMT is further refined as

> *'technologies that have a demonstrated track record of being technically effective and economically viable on an industrial scale for minimizing the discharge of pollutants from (in the Tasmanian case) bleached eucalypt kraft pulp mills to the environment.'*

These technologies have been accepted as an integral part of worldwide supra-national, national and sub-national environmental guidance.

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[15] Resource Planning and Development Commission: *Development of new environmental emission limit guidelines for any new bleached eucalypt kraft pulp mill in Tasmania,* Aug 2004
http://www.rpdc.tas.gov.au/bekm/final_report
http://www.rpdc.tas.gov.au/bekm

[16] Study report for Independent Advice on the development of new environmental emission limit guidelines for any new bleached eucalypt kraft pulp mill in Tasmania, Aug 2004. http://www.rpdc.tas.gov.au/bekm/final_report
http://www.rpdc.tas.gov.au/bekm

Another term introduced in the mid-90s is Best Available Techniques. The EU established a set of common rules for permitting and controlling industrial installations in their IPPC Directive of 1996. IPPC is the acronym for Integrated Pollution Prevention and Control. Best Available Techniques (IPPC-BAT), are defined in the EC Directive[17] 96/61 as

> *"the most effective and advanced stage in the development of activities and their methods of operation which indicate the practicable suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent, and where that is not practicable, generally to reduce the emissions and the impact on the environment as a whole".*

Article 2(11) goes on to clarify IPPC-BAT as follows:

- "techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- "available" techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
- "best" means the most effective in achieving a high general level of protection of the environment as a whole.

Note that implementation of state-of-the-art technology alone is insufficient to guarantee IPPC-BAT is achieved. It is critical that the equipment be well-operated and maintained to ensure operating objectives are consistently met over the long term. These aspects touch on the permitting process, permit requirements and enforcement.

Another term is Best Available Control Technology used by the US Environmental Protection Agency (US EPA). Introduced with the Clean Air Act Amendments of 1977, new sources are required to use Best Available Control Technology (US-BACT) in cases where air quality is already impaired. The establishment of BACT is a process rather than a prescribed list of required technology and systems, the approach used by the EU and Tasmanian governments. BACT is based on precedent within the industry by reference to recent BACT rulings. Establishing BACT involves Identifying all control technologies, eliminating the technically infeasible options, ranking remaining control technologies by emission control performance, and evaluating the controls as to cost effectiveness. The results are part of the application presented to the regulatory authority which initiates a process of negotiation that results in the selection of BACT for the particular project.

It is noted that BACT makes no direct reference to operation and maintenance. A related term Best Available Technology (EPA-BAT) came into use when in April 1998 the US EPA promulgated the 'Cluster Rule'. This rule was introduced to protect human health and the environment by reducing toxic releases to the atmosphere and aquatic environment from U.S. pulp and paper mills. The final water rule includes best available technology limits. EPA-BAT

[17] EU integrated pollution prevention and control (IPPC) which may be found at: http://eippcb.jrc.es/pages/FActivities.htm

in the US is defined as the best control and treatment measures that have been or are capable of being economically achieved.

A more detailed summary of US-BACT and the permitting process is provided in Appendix B - Air Emission Regulations and Management Measures.

3.2 Accepted Modern Technology and Best Available Techniques

The technology and operating techniques associated with AMT and IPPC-BAT are summarized in this section as both have been developed most recently: IPPC-BAT with the issue of the IPPC Bref in 2001 and AMT in 2004. As AMT was conceived for permitting a completely new greenfield mill, it is more restrictive and offers less latitude to meet best current practice than the more general IPPC-BAT requirements which applies to new mills in existing mill sites. In the few cases where the older US regulations prescribe more specific technological approaches or limits, these will be presented. This is the case for NCG venting allowances, and is discussed in Section 4 - Odorous Gas Venting.

The technologies that are considered AMT for the reduction of emissions to the atmosphere are presented in Table 3.1.

Table 3.1– AMT for the reduction of emissions to the atmosphere

Chlorine dioxide and related compounds [a]	• Collection and scrubbing in the bleach plant scrubber, which uses alkaline scrubbing media • Collection and scrubbing in the chlorine dioxide plant environmental scrubber, which uses alkaline scrubbing media
Dioxins and furans	• Inhibiting the formation of dioxins and furans within power and recovery boilers by appropriate design to achieve the most suitable time/temperature profile, and by appropriate operation including control of oxygen content, instituting systematic sootblowing, and the firing of fuels having minimum contamination with dioxins, furans and their precursors to minimise dioxins and furans in the flue gases[d]
Inorganic chlorinated compounds [a]	• Collection and scrubbing in the bleach plant scrubber, which uses alkaline scrubbing media • Collection and scrubbing in the chlorine dioxide plant environmental scrubber, which uses alkaline scrubbing media
Nitrogen oxides (NOx)	• For the recovery boiler: control of combustion temperature profile; air distribution and excess air; and black liquor nitrogen content; and also appropriate design (low NOx) • For the lime kiln: control of firing conditions and also appropriate design (low NOx) • For the power boiler: control of firing conditions and also appropriate design (low NOx)
Particulate matter (PM) or dust	• Cleaning of the flue gases from the recovery boiler, the power boiler (in which other biofuels or fossil fuels, or both are burned) and the lime kiln with efficient electrostatic precipitators
Sulphur dioxide (SO_2)	• For the recovery boiler: firing of black liquor with high dissolved solids concentration to mitigate SO_2 formation or flue gas scrubbing, or both • For a standalone CNCG incinerator: flue gas cooling with either a

	steam boiler or quench coolers and flue gas scrubbing • For the power boiler: use of bark, gas, low-sulphur oil, low-sulphur coal or flue gas scrubbing
Total reduced sulphur (TRS)	• Collection and incineration of concentrated non condensable gases (CNCG) in either the recovery boiler or a standalone low-NOx incinerator [b] • Backup system for the CNCG – which is activated during upsets, maintenance or other downtimes of the main system – consisting of: • A flare/incinerator and secondary incineration unit (e.g. the lime kiln), or • A pre-purged alternative disposal point immediately available with interlocks permitted to allow switching without venting (bumpless transfer) to a power boiler • Collection and incineration of dilute NCG (DNCG) in the recovery boiler after their addition to its secondary or tertiary combustion air [c] • Methanol recovery from the foul condensate stripper off-gases • For the recovery boiler: computerised combustion control and carbon monoxide (CO) measurement • For the lime kiln: control of the excess oxygen, use of low sulphur fuel, and control of the residual soluble sodium in the lime mud fed to the kiln • Spot monitoring program carried out by measuring odour with a mobile gas chromatograph/mass spectrometer (GC-MS). Testing will be more frequent initially and less frequent later in the program

Notes:
a - Small amounts of elemental chlorine are produced when chlorine dioxide reacts with the pulp in ECF bleaching.
b - Sources for CNCG are the digester plant, the vacuum system of the evaporation plant and the foul condensate stripper.
c - Sources of DNCG are the fibreline process vents, tank vents, chip bin vents and include the smelt dissolving tank (SDT) vent. The SDT vent is cooled and scrubbed before being piped to the recovery boiler.
d - This is also considered a best available technique (IPPC-BAT) for the purposes of the Stockholm Convention on Persistent Organic Pollutants.

A summary of IPPC-BAT from the reference[18] is:

• Collection and incineration of concentrated malodorous gases from the fibre line, cooking plant (digester), evaporation plant, condensate stripper, and control of the resulting SO_2. The strong (concentrated) gases can be burned in the recovery boiler, the lime kiln or a separate, low NOx furnace (NCG incinerator). The flue gases of the latter have a high concentration of SO_2 that is recovered in a scrubber.

2. Collection and incineration of diluted malodorous gases from, for example, the fibre line, various sources as tanks, chip bins, smelt dissolver etc. The weak (dilute) malodorous gases can be burned in, for example, the recovery boiler mixed with combustion air or in an auxiliary boiler depending on the volume.

3. Mitigation of the TRS emissions of the recovery boiler by computerized combustion control and CO measurement and in the case of the lime kiln by controlling the excess oxygen, by using low sulphur fuel, and by controlling the residual soluble sodium from the lime mud fed to the kiln.

[18] EU integrated pollution prevention and control (IPPC) which may be found at: http://eippcb.jrc.es/pages/FActivities.htm

4. Control of SO_2 emissions from the recovery boilers by firing high dry solids concentration black liquor in the recovery boiler to mitigate SO_2 formation and/or by using a flue gas scrubber.

5. Control of NO_x emissions from the recovery boilers and lime kiln by controlling the firing conditions and by ensuring proper mixing and division of air in the boiler, and for new or altered installations also by appropriate design;

6. Control of NO_x emissions from auxiliary boilers by controlling firing conditions and for new or altered installations also by appropriate design.

7. Reducing SO_2 emissions from auxiliary boilers by using bark, gas, low sulphur oil and coal or controlling sulphur emissions with a scrubber.

8. Cleaning of the recovery boilers, auxiliary boilers (in which other biofuels and/or fossil fuels are incinerated) and lime kiln flue gases with efficient electrostatic precipitators to mitigate dust emissions.

Other IPPC-BAT measures mentioned in the EIA for two recent Uruguayan pulp mills [19] are:

- Application of cogeneration to the supply of heat and power.
- Use of renewable sources of fuel, such as wood or wood waste in auxiliary boilers to reduce the emission of fossil CO_2.

The IPPC-BAT recognizes that to be effective best available process technologies must be implemented in combination with the following operating and maintenance practices:

- Training, education and motivation of staff and operators.
- Process control optimisation.
- Sufficient maintenance of the technical units and the associated abatement techniques; and
- Environmental management system which optimises management, increases awareness and includes goals and measures, process and job instructions, etc.

A brief summary of the common pulp and paper processes and air emission control technologies is presented in Appendix C - Mill Processes, their Air Emissions and Controls.

[19] *Cumulative Impact Study – Uruguay Pulp Mills*, EcoMetrix Incorporated, Sept 2006. http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/$FILE/Uruguay_CIS_AnnexC_Oct2006.pdf

4.0 ODOROUS GAS VENTING

This section describes why the venting of sulphurous odour gases occurs, tabulates 2005 venting data for Alberta kraft pulp mills and compares the results with best current practice and US venting regulations.

4.1 Description

Historically, one of the most characteristic and negative features of a kraft pulp mill to humans has been the strong odour of the sulphur-based gases that are emitted. Today odour levels are much reduced by technological advances and most mills normally emit no discernable odour. People can smell H_2S, one component of Total Reduced Sulphur (TRS) gases, at very low concentrations. The odour detection threshold of H_2S is in the 0.4 – 10 parts per billion range, whereas most odorous gases are detected by the human nose in the parts per million range. These gases are often described as smelling like rotten eggs, or the odours given off by town sewers. Physical health effects from TRS gases occur in the parts per million range, that is, at about 1000 times the concentration that the human nose can first detect H_2S. After exposure to low levels of TRS gases over time, people loose the ability to smell them at very low concentrations. For this reason some mills use "citizen panels or networks" to help identify odour events in a community. One component of TRS gas, H_2S has a particularly dangerous characteristic in that it is not smelt at high health-threatening concentrations due to olfactory fatigue. Safety requires the use of local alarms for workplaces so affected.

TRS gases are a mixture of hydrogen sulphide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulphide ($(CH_3)_2S$), and dimethyl disulphide ($(CH_3)_2S_2$). The main generation of TRS occurs in the wood cooking process, when sulphide in cooking liquor (sodium sulphide) reacts with methyl groups in the wood. These TRS materials are volatile, with the boiling points of hydrogen sulphide (- 62°C), methyl mercaptan (6°C), dimethyl sulphide (38°C), and dimethyl disulphide (118°C). These low boiling points mean that these gases can volatilize in the liquor system. The hydrogen sulphide and methyl mercaptan emissions are strongly influenced by pH, being held more strongly in alkaline solution. Liquor pH is the most important control parameter for H_2S and CH_3SH emissions from liquid to gas phase, while emissions of other organic sulphides are controlled by manipulating the liquor temperature.

The most severe odour episodes occur at kraft pulp mills when non condensable gases (NCG) that is normally incinerated is released untreated ("vented ") to atmosphere. This generally occurs during a period of abnormal system or mill operation. These releases of untreated NCG will typically only occur during periods of abnormal operation involving mill or process upset, start-up or shutdown; malfunction of controls or equipment; mechanical failure (blower or rupture disk) which prevents incineration of concentrated non condensable gases (CNCG) or dilute non condensable gases (DNCG) in the primary or back up incineration device. In older systems, there may also be short term releases when incineration is switched from one device to another, say from a kiln to a power boiler, which requires purging of lines to atmosphere.

In addition, there may be releases from emergency vents for overpressure relief. These discharges consist of flashing steam, and vapours containing NCG that can be released from the digester area. These are typically rare occurrences and events of brief duration. Emergency vent lines are typically led to a pulp mill standpipe which directs the gases to roof top as an operator health and safety measure. These sources are not considered candidates for treatment because the releases occur briefly during rare emergency conditions.

4.2 Regulatory Approaches to Venting

4.2.1 Alberta

Among the Canadian provinces, Alberta Environment is believed to be unique in specifically limiting the number of hours per month that a mill is allowed to vent NCG emissions to the atmosphere. A reading of the Alberta mill permits indicates that there is no exemption on venting when associated with start-up, shutdown and NCG system malfunction. However, the wording of some of Alberta kraft pulp mill permits leaves room for ambiguity in what is counted toward venting time, for example, releases from water seals in NCG collection systems, which may not be named sources.

The permitted venting time for the 4 Alberta kraft pulp mills is presented in Tables 4.1 and 4.2.

Table 4. 1 - Monthly Permitted Venting Limits - Concentrated NCG

	CNCG h	SOG h	INCG h	Chip Bin h	Total h	% of time (a)
Boyle	-	-	-	-	12	1.6%
GPrairie	12	12		8	32	4.4%
Hinton	8	4	15		27	3.7%
Peace R	8	8	-	-	16	2.2%

Note: a - Assumes 8760h/a

Table 4. 2 – Monthly Permitted Venting Limits - Dilute NCG

	DNDG h	% of time (a)
Boyle	12	1.6%
GPrairie	12	1.6%
Hinton	15	2.1%
Peace R	24	3.3%

Note: a - Assumes 8760h/a

4.2.2 The US

The US EPA's Cluster Rules promulgated in 1998 were aimed at reducing HAPs. Under these Rules, Maximum Achievable Control Technology (MACT) provisions requires that by April 2001, existing mills will have to have CNCG (including the stripper off-gas) and DNCG systems that meet the destruction efficiency, oxidation conditions and uptime criteria shown in Table 4.3.

Table 4. 3 - MACT Requirements for NCG Incineration Performance

	CNCG & SOG	DNDG
Destruction efficiency	>98.0	-
Destruction conditions	871°C (1600°F), 0.75s	871°C (1600°F), 0.75s
Availability, %	>99.0	>96.0

For new mills these performance requirements came into effect in April 1998.

The Cluster Rule does not specifically require redundant or back-up systems for either the CNCG or the DNDG system, as the availability requirements effectively define the required performance, leaving the particular means up to the mill.

An additional requirement under the Rule is that a Start-up, Shutdown and Malfunction (SSM) plan must be drawn up for the NCG systems, recognizing that for safety, maintenance or other reasons these gases must, from time to time, be vented to atmosphere. The Rule provides that, in addition to these SSM venting times, there is an additional 1% of operating time in the case of CNCG systems, and 4% in the case of DNCG systems, as a maximum allowance for venting downtime.

The SSM Plan requires detailed record-keeping and planning that is clearly defined and includes:

- Corrective action steps to be taken in the event of a malfunction
- Procedures to be followed during start-up, shutdown and malfunction and refinement of these procedures to limit venting as experience is gained
- Quality assurance / quality control requirements for the monitoring system, and
- Preventative maintenance requirements and updating of these maintenance procedures in order to reduce down-time as experience is gained.

Failure to follow these steps and procedures voids the venting episode being considered as allowable under the regulation. These types of emissions would then be counted toward the downtime allowable.

All venting from the system must be recorded and the formal logs and records retained. Proof of compliance must be provided on a continuous or near-continuous basis. If the venting exceeds maximum downtime allowance on a semi-annual basis, it is considered as a violation.

4.3 Benchmarking Venting Durations

4.3.1 Alberta mills

The NCG venting times are recorded for the four Alberta kraft pulp mills as required by their permits. Data for 2005 is presented in Tables 4.4 and 4.5 as a percent of hours per year. The hours per year is taken as 8760.

Table 4.4 – Annual Venting Time - Concentrated NCG

	CNCG h	SOG h	Total h	% of time (a)
Boyle	22.2	Included	22.2	0.26%
GPrairie	5.4	1.4	6.8	0.08%
Hinton	22.4	4.8	27.2	0.32%
Peace R	8.2	10.6	18.8	0.22%

Note: a - Assumes 355 operating days/a

Table 4.5 - Annual Venting Time - Dilute NCG

	DNCG h	Chip Bin h	Total h	% of time (a)
Boyle	9.4	2.6	12.0	0.14%
GPrairie	9.3(b)	6.9	16.2	0.19%
Hinton	43.9	Included	43.9	0.52%
Peace R	127.2	Included	127	1.5%

Note: a - Assumes 355 operating days/a
b - Lean gas from tanks and evaps + BS washers

4.3.2 Some newer mill results

The downtime or lack of availability of the CNCG collection and oxidation systems of several best practice modern pulp mills has been reviewed as part of a design review of the proposed greenfield mill in Tasmania, Australia[20] and is summarized in this subsection.

The total annual durations of venting directly to atmosphere of three Swedish pulp mills are presented in Table 4.6. These statistics include start-ups, shutdowns, process upsets and equipment malfunctions. All of the mills have been operating for a number of years, and all have a primary incineration system with a single back-up available when the pulp mills are operating.

Table 4.6 - CNCG Venting by Three Swedish Pulp Mills

	Mill A (a)	Mill B (a)	Mill C (a)
Venting hours per annum	9	14	5
% of operating time	0.11%	0.16%	0.06%

NOTE: a - Swedish mills cited in Tasmanian Pulp Mill, Draft integrated Emission Statement, Vol1B, Introduction and Overview, July 2006[21].

Mills A, B and C were not identified in the reference material due to commercial-in-confidence considerations. No venting duration information is available for DNCGs.

[20] Gunns Bell Bay Pulp Mill, *Draft integrated Emission Statement*, Vol1B, *Introduction and Overview*, July 2006. http://www.gunnspulpmill.com.au/IIS/

[21] Gunns Bell Bay Pulp Mill, Draft integrated Emission Statement, Vol1B, Introduction and Overview, July 2006. http://www.gunnspulpmill.com.au/IIS/

This is very good performance and since venting time associated with start-ups, shutdowns and periods of malfunction is included, is much better than the US Cluster Rules in the US which allow 1% of the time, or 88h per year, for CNCG venting. Note however that the US Cluster Rule limit applies to all existing mills of which some are using older, less sophisticated systems.

CNCG and DNDG venting data reported to the regulatory authorities for several US mills is presented in Table 4.7. In this case, all venting associated with start-ups, shutdowns or malfunctions has been excluded.

Table 4.7 - CNCG and DNCG Venting from Four Older US Pulp Mills (Excludes all venting during Start-ups, Shutdowns or Malfunctions)

	Mill 1 (a)	Mill 2 (b)	Mill 3 (b)	Mill 4 (b)
CNCG				
Hours per annum	2	3.5	30.1	35
% of operating time	0.023	0.04	0.35	0.4
DNCG				
Hours per annum	-	192	<<440	<35
% of operating time	-	2.2	<<5	<0.4

NOTES: a - Client confidential mill visit report. DNCG venting of 7h/a for this mill. Data from mid-90s

b -. In-house data.

The CNCG venting data for the four Alberta mills, the three Swedish and four US mills is presented together in Fig 4.1. It is noted that presenting these data together ignores the fact that the Swedish mill data and that of the Alberta kraft pulp mills includes the venting occurring during start-ups, shutdowns or malfunctions, whereas the US mills exclude such venting time. Despite this discrepancy, it is seen that, even with this extra burden, the three Swedish mill venting times and that of the best performing Alberta mill are comparable with the best of the US mills.

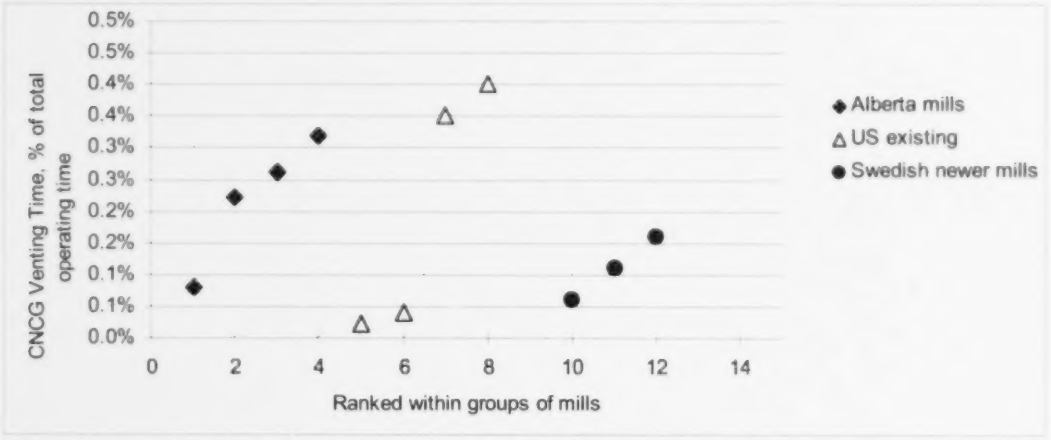

Figure 4.1 - CNCG Venting Times Compared with US and Swedish

More specific information on EU venting emission monitoring management is presented in the reference[22] and is reproduced here:

> "ENCE's Huelva and Pontevedra mills were visited by a member of the CIS team in Spain. Both mills have certified environmental management systems (EMS), which include recording of environmental complaints, observations and inquiries from members of the public or employees. The record of complaints was reviewed for odour-related complaints. For the Pontevedra bleached kraft eucalypt mill, from October 4th 2005 to August 1st 2006, 31 complaints were recorded relating to noise, odour, black smoke, and fire/fire, of which a total of 5 were related to odour.
>
> In a similar manner the records from October 28th 2004 to June 7th 2006 at the ENCE Huelva were examined. There were 61 environmental notifications, and not one was an odour complaint. At the ENCE mill in Huelva, Southern Spain, a record of venting of the concentrated NCG system is kept and reported on. The collection of concentrated odorous gases opened the safety valve in 2005 for a total of 47 times, for a period of more than 30 seconds for a total vent time in 2005 of less than 24 minutes. This venting time is remarkably short."

The advanced air dispersion modelling undertaken for new mills using the more sophisticated models available today would allow projections of episodes of nuisance odour due to excessive ambient TRS concentrations to be estimated from the frequency and duration of peak TRS discharges from mill sources. These latest modeling techniques allow evaluation of the impact of potential near ground level sources such as from secondary effluent treatment plants.

[22] Cumulative Impact Study for two recent Uruguayan pulp mills: Cumulative Impact Study – Uruguay Pulp Mills, EcoMetrix Incorporated, Sept 2006.
http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/$FILE/Uruguay_CIS_AnnexC_Oct2006.pdf

5.0 OVERVIEW OF KEY REGULATIONS ELSEWHERE

5.1 *Introduction*

This section provides a summary of regulation in the US and the EU, jurisdictions that are at the forefront of pulp and paper regulations worldwide and therefore the more relevant regulations for purposes of this report. The World Bank's guidelines applicable in the developing world are also included, particularly since their new more definitive and demanding guidelines issued in 2007 generally reflect up to date best practice.

This section outlines the regulatory process behind the guideline limit values. The emission limit values themselves were presented in Table 2.4 - *Emission Permit Limit Comparison for Selected Jurisdictions* of Section 2.2.

With the focus of this section on the US, the EU and the World Bank regulations, more detailed information on these and the other jurisdictions, namely, those of:

- the Canadian Provinces of BC, Ontario and Quebec;
- Finland; and
- Sweden.

are to be found in Appendix B - Air Emission Regulations and Management Measures.

The Tasmanian Government has issued guidelines for the construction of a bleached eucalypt kraft pulp mill, and some of the air emission limit values and web addresses where they may be found are presented in Section 3 - Technology Used in New World Class Kraft Pulp Mill Designs. Though referenced, this jurisdiction is of less interest as Tasmania has no existing kraft pulp mills, and therefore is not discussed further.

The environmental permitting practices for pulp and paper mills in ten countries in North America and Europe were reviewed by the Organization for Economic Co-operation and Development (OECD)[23]. Although published 8 years ago, it makes the following relevant generalizations which are still valid:

- permit criteria stated in national or state legislation result from a balancing of the environmental quality objectives for the air shed (receiving environment) and what current best practice can reasonably achieve in terms of the mill emission control performance.
- Emission limits as established in standards or guidelines are considered, then the site-specific conditions of topography, meteorology and mill configuration and characteristics (stack heights, mass emission rates and velocity) are evaluated by air dispersion modeling

[23] Organization for Economic Co-operation and Development, Environmental Requirements for Industrial Permitting – Case Study on the Pulp and Paper Sector – Parts 1 and 2: http://72.14.205.104/search?q=cache:rZ0r5C0KzfEJ:www.olis.oecd.org/olis/1999doc.nsf/3dce6d82b533cf6ec125685d005300b4/42a48b97f9adcae8c12567ed005e1ed9/%24FILE/09E98927.ENG+ENV/EPOC/PPC(99)8/FINAL/PART1&hl=en&ct=clnk&cd=2

often supplemented by ambient air quality sampling to determine the impact on the existing air shed.

In general, the air emission permitting process comprises the following elements:

- Mill operating permits, licences, or construction permits are the means used by governments ensure that air and other emissions from pulp and paper mills are controlled to levels that adequately safeguard public health and the environment. Mill permits are often set to be more restrictive than regulations, standards or guidelines, and permits often limit emissions for which there are no corresponding regulations.
- In most countries, regulations including permit limit values that apply to new pulp and paper facilities are also applicable to any rebuild or replacements of equipment in an existing a mill where the changes are major, while lesser modifications are exempt. A modification may be defined as 'major' by the additional mass rate of air emission, the amount of production increase, or an assessment by an authority of the significance of a change.
- More stringent requirements in regulations and permits are applied to new mills than existing mills. New mill permit limit values should be established by considering the existing ambient air quality in the vicinity of the mill. This requires dispersion modeling of the new or modified discharges to determine their effect on ambient air quality.
- A number of jurisdictions have mechanisms in place or planned that require existing mills to meet more restrictive emission limits in renewal of their operating permits, even if they are not undergoing any significant change.

5.2 *US Regulations*

The most significant change in permitting practice in recent years in the US has been the introduction of Maximum Achievable Control Technology (MACT) requirements for both existing and new sources. Mandated under Title III of the 1990 Clean Air Act Amendments, the National Emission Standards for Hazardous Air Pollutants (NESHAP)[24] identifies a list of 189 Hazardous Air Pollutants (HAP) and 174 categories of sources and requires all process discharges to use MACT. These regulations to protect human health and the environment are called the 'Cluster Rules' as they integrate the rule-making for discharges to water, land and air to ensure comprehensive control of HAPs.

Key aspects of MACT are:

- methanol is used as a surrogate for total HAPs for all pulping vents, which therefore includes TRS and imposes collection and treatment of concentrated and dilute NCG sources; and
- particulate matter are used as a surrogate for total metals for recovery boilers.

[24] http://www.epa.gov/ttn/uatw/pulp/pulppg.html

Prior to the Cluster Rule, the New Source Performance Standards (NSPS) for kraft pulp mills first promulgated in 1978 and added to subsequently, established emission limits for PM, TRS and opacity from the main kraft pulping emission sources. The introduction of the MACT requirements has for most sources superceded NSPS.

After many years in development, and several draft issues, MACT for industrial boilers was due to come into effect in September 2007. This rule covering power boilers typically found in mills met a legal challenge in the summer of 2007 and has been withdrawn by the US EPA. The rule would have limited PM, total selected metals, HCl, Hg, and CO. However, as of June 2007, revised NSPS standards have been introduced for existing and new industrial boilers. Though these standards only limit NOx, PM and SOx they are more restrictive than previous NSPS limits, though the PM limit is less demanding than that of the proposed MACT Rule.

5.3 *EU Regulations*

Since 1996, the European Union (EU) has a set of common rules on permitting for industrial installations called the Integrated Pollution Prevention and Control (IPPC) Directive. The Directive aims to minimize point source pollution throughout the EU and incorporates integrated permitting that must take into account all aspects of environmental performance. The IPPC Directive is based on four principles:

- ***An integrated approach*** The integrated approach means that the permits must take into account the whole environmental performance of the plant, covering e.g. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure.
- ***Best Available Techniques*** The permit conditions including emission limit values must be based on Best Available Techniques (IPPC-BAT) , as defined in the IPPC Directive. To assist the licensing authorities and companies to determine BAT, the Commission publishes BAT Reference Documents, the so-called BREFs. These are based on reports by experts and consultations with EU Member States, industry and environmental organisations.
- ***Flexibility*** The IPPC Directive contains elements of flexibility by allowing the licensing authorities to determine permit conditions that take into account:
  (a) The technical characteristics of the installation;
  (b) Its geographical location; and
  (c) The local environmental conditions.
- ***Public Participation*** The Directive ensures that the public has a right to participate in the decision making process and to be informed of its consequences by requiring access to permit applications, permits, the results of the monitoring of emissions and the European Pollutant Release and Transfer Register, where emission data is made accessible in a public register.

Each EU member country must issue its own operating permits to existing and new pulp and paper facilities. Implementation of the permit and compliance monitoring remains within the authority of each Member State, but specific limits must be as stringent as the IPPC Directive

conditions. Member States can decide to implement permitting in a phased approach to avoid any economic disadvantages to older facilities that may require radical environmental improvements to achieve IPPC-BAT.

For the pulp and paper industry the first BREF report was published by the European Commission in December, 2001. Along with background on the industry in the EU, the BREF contains a description of process technologies and the technologies and operating techniques that reflect IPPC-BAT and the emission value or range of achievable emission levels.

An important clarification to the BREF document appeared in a December 2007 document[25] as to why it is wrong for IPPC-BAT emission limit values to be used as permit limit values:

- BAT levels are based on annual averages, which "…cannot be used in permit limits…", which we interpret to mean are insufficient to define the limits required for effective permits.
- Permit limits are based on National Legislation
- The Local environmental and socioeconomic conditions need to be taken into account in permit limits. The local conditions can either tighten or loosen the permit limits.
- Site-specific factors, for example technical characteristics of a mill and its product portfolio, must be considered in the permitting process and for the permit limits.
- The BAT values presented in BREF are not generated in a systematic way as they are taken from heterogeneous data sources.

The range of IPPC-BAT limit values along with those of other jurisdictions are presented in Table 2.4 at the end of Section 2.

The most recent figures on the issuing of permits under the Directive suggest that by mid-2006 only about 50% of the 52,000 installations concerned had received a permit. Reasons given for the lack of progress include:

- The weakness of existing legislation, so that there has not been the same degree of application of BATs required by the IPPC Directive across the EU.
- Compliance with and enforcement of current legislation in the different Member States is also inconsistent.
- The complex legal framework carries unnecessary costs for industry.

Recognizing the shortcomings of the process, on 21 December 2007 the European Commission[26] adopted new to strengthen the provisions already in force. These issues need to be addressed in order to maintain a level playing field for industry while offering higher levels of protection for the environment and human health.

[25] http://www.ymparisto.fi/download.asp?contentid=65130&lan=EN

[26] http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1985&format=HTML&aged=0&language=EN&guiLanguage=en

5.4 *World Bank Regulations*

Pulp and paper industry projects that solicit and use financing from the World Bank Group (WBG) must comply with their policies and guidelines which emphasize pollution prevention, including the use of cleaner production technologies.

One of several members of the Group is the International Finance Corporation (IFC), with the mandate of the promotion of economic development through partnership with the private sector. The IFC is often involved with new pulp and paper mills in the developing world.

The WBG have recently updated their guidelines in 2007.

Their Environmental, Health, and Safety (EHS) Guidelines are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them. The EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account.

An initial environmental assessment is required to show that ambient air quality guidelines, whether national or those of the World Health Organization, are met. The contribution of the project should not exceed 25% of the ambient air quality guidelines, based on local air quality assessments and dispersion modeling using internationally recognized software and procedures. Special requirements would be sought in the case of degraded air sheds that do not meet ambient air quality guidelines.

The EHS Guidelines for pulp and paper mills recommends modern technology and systems design such as: CNCG collection and incineration with a backup; a DNCG system with a backup incineration if close to residential areas; firing black liquor at 75% solids or higher; etc..

The Guidelines also include requirements covering fugitive and greenhouse gas emissions and energy conservation. Annexes to these Guidelines describe modern pulp and paper process technologies in use today, and give Guideline values for emissions, electrical and heat energy use rates and water consumption on a per tonne basis.

At the end of Section 2.2, Table 2.4 - *Emission Permit Limit Comparison for Selected Jurisdictions* presents the World Bank Guideline emission limit values for kraft pulping.

6.0 CO_2 EMISSIONS AND ENERGY EFFICIENCY

This section addresses the emissions of the principal greenhouse gas CO_2 and its control.

The industry burns large quantities of biomass fuels such as pulping liquors, wood waste and bark but the associated CO_2 releases are not included in greenhouse gas emissions since the carbon in these materials is of biogenic origin and part of a natural cycle. This renewable biomass-derived CO_2 is "carbon neutral", though strictly speaking, there are comparatively small amounts of gases in the products of combustion with greenhouse warming potential such as nitrous oxide which are also emitted during the combustion of biomass fuels just as they are with fossil fuels.

It is the combustion of non-renewable fossil fuels such as gas, oil and coal in the pulp and paper industry that is responsible for virtually all of the additions to greenhouse gases. These consist primarily of CO_2.

Accordingly, non-renewable CO_2 emissions control focuses on reducing the use of fossil fuels. This is achieved by the displacement of fossil fuels by biomass fuels, and using energy more efficiently.

6.1 Energy Conservation and Benchmarking

The pulp and paper industry relies heavily on carbon-neutral biomass fuels that reduce atmospheric levels of greenhouse gases to meet its large energy needs and these fuels displace fossil fuels. Accordingly, CO_2 emissions control is focused on non-renewable sources of CO_2 which are the fossil fuels, gas, oil and coal.

Control of CO_2 emissions from these non-renewable fuels is therefore a matter of minimizing fossil fuel use by making the best use of energy in the mill and minimising waste and losses. This is achieved by:

- adopting energy efficient processes;
- using high efficiency equipment;
- minimizing heat losses by improving process thermal integration; and
- maximizing power generation from biomass and maximizing the more efficient backpressure generation over condensing generation and exporting the surplus.

The latest kraft pulp mills have surplus power which they export. This is significant in Alberta where purchased power will be from coal fired condensing power type plants with a significant carbon emission associated with it.

All of these measures can only be implemented to the extent that they are economically justified, and justification is much harder in an old mill than at the design stage of a new mill.

6.1.1 What can be done in existing mills now?

There seems to be a growing recognition that pro-active management of energy costs and efficient energy use must be part of company strategy over the long term. The recommended approach involves setting up a process as much as investing capital on projects.

The first step is to establish a process with the objective of instilling an energy efficiency culture in the mill. Two decades ago that culture was pervasive in the industry. The culture was the response to the high prices of purchased energy and it drove energy cost savings efforts. This focus on conservation and energy efficiency subsided by the mid-1980s paralleling the decline in oil prices.

With energy prices high once again, an energy efficiency program is seen as the obvious thing to do and involves the following steps:

1. Obtain management commitment to a sustained process of continuous energy efficiency improvement analogous to Total Quality Systems and Environmental Management Systems.
2. Establish an energy efficiency team and appoint an appropriate leader, or 'Champion' with a mandate to set up an energy efficiency program, set objectives, estimate resources and set out a schedule.
3. Develop the energy efficiency program which would comprise:
    a. Undertaking a detailed energy audit of the mill.
    b. Assessing the adequacy of the existing mill energy reporting system - is it meeting the needs of the end user? Recognize that we can't improve performance, if we don't measure it, or if we don't measure the right things, or if the right people don't see the right information.
    c. Benchmarking specific energy consumption at the department level and the overall mill level, tracking over time the progress in reducing the mill's energy use, and determining gaps with other like mills and new mills.
    d. Identifying, evaluating and screening projects with apparent potential.
    e. Analysing by a variety of measures:
        i. the return on investment,
        ii. energy cost reduction per tonne production,
        iii. greenhouse gas reduction,

    then ranking and selecting the groups of projects to implement.
4. Implement projects, conduct post-start-up audits to determine the savings actually achieved, provide on-going monitoring and reporting of results, conduct management review and apply corrective action as needed.

Regular audit-based energy benchmarking, even if limited to self-benchmarking, allows a mill to track progress and establish the gap with published data on mills of newer, more modern design.

For further information on the steps in implementing an energy efficiency program, a brief summary of the detailed energy audit, energy efficiency improvement opportunities in older

mills, procurement strategies, operations and maintenance, retrofits and new technology are included in the reference.[27] The Canadian manual provides more complete information.[28]

A comment on pinch analysis from that reference is relevant:

> Large multi-line pulp or integrated mills are complicated, and far-reaching and sometimes unsuspected interdependencies exist between unit processes because of piecemeal changes and lack of documentation of the mill's energy flows. In these situations, pinch analysis, a relatively new analytical tool for the evaluation of process thermal integration is increasingly being used and found to be useful. Pinch analysis defines the thermodynamically minimum energy use required to meet a mill's requirements. This allows setting practical "targets" for steam generation and heat rejection. The gaps identified are great motivators to improve.
>
> Initial development of pinch analysis was by individuals with backgrounds in the chemical and petrochemical industry, and it was in that industry where the first applications arose. The technique was found to be very valuable in analysing complex systems involving many heat exchangers where the total possible number of different configurations is obviously very large. So far, the use of pinch analysis in pulp and paper has lagged behind these industries. The reason is probably that, in pulp and paper, some of the processes are already well integrated and the heat exchanger networks are simpler, making the integration opportunities more obvious such that the heat integration has become a matter of standard practice. Also, the dispersed nature of pulp and paper mill site layouts possibly restricts options more than in the chemical and petrochemical industry. Pinch analysis is not effectively summarised in a few words without introducing examples, but good references exist[29,30].

A study which assessed the potential of pinch analysis to reduce greenhouse gas emissions if applied to the whole of the Canadian pulp and paper industry[31] estimated from early data that process heat, mainly steam, would be reduced by 7.8% based on a sampling of actual projects resulting from pinch studies. At the study stage, projected savings range typically between 10 – 30%. However, anecdotal information since has indicated that while the actual reductions achieved vary widely the average reduction is likely to be much larger.

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[27] D. Bruce, B Brander, C. Kershaw: *Greenhouse Gas Emission Reduction Through The More Efficient Use Of Energy In Existing Pulp And Paper Mills*, the 54th APPITA Conference April 2000, Melbourne, Australia; published in APPITA Journal, Vol 54, No. 2, March 2001.

[28] Browne, T.C. (tech.ed.) *Energy Cost Reduction in the Pulp and Paper Industry*, Pulp and Paper Research Institute of Canada, February, 2000. Distributed by the Pulp and Paper Technical Association of Canada..

[29] Linnhoff, B., Townsend, D.W., Boland, D., Hewitt, G. F., Thomas, B. E. A., Guy, A. R., Marsland, R. H. A. - A user guide on process integration for the efficient use of energy, Institute of Chemical Engineers, Rev 1, 1982

[30] Litzenberg, B., Gill, J., Retsina, T: *Pinch Analysis Reveals Potential at Bowater's Calhoun Tennessee Mill*, proc. TAPPI Pulping Conference, 1999.

[31] D. Bruce: Government of Canada, Forest Sector Table, National Climate Change Process, Ottawa, ON: Study of the potential for the reduction of energy use and greenhouse gas emissions by the Canadian pulp and paper industry through improved process thermal integration using 'Pinch Analysis' techniques, based on a survey of case study results.

6.2 *Current Best Practice in Newer Mills*

Newer pulp mill designs will typically have significantly lower energy use per tonne of product than the newest of the Alberta kraft pulp mills, the Alberta Pacific Forest Industries mill at Boyle. As well, the new mills use proportionately more energy in the form of power and less as steam than the older mills. The Boyle mill itself uses significantly less than typical older pulp mills in Canada, though the scope of this study did not include the collection and analysis of energy consumption data.

6.2.1 *Best design practice*

A summary of the measures that IPPC-BAT proposes be considered is provided in the reference[32]:

- high dry solids content of black liquor and bark;
- high efficiency of steam boilers, e.g. low flue gas temperatures;
- effective secondary heating system e.g. hot water about 85°C;
- well closed-up water system;
- relatively well closed-up bleaching plant;
- high pulp concentrations in process (so-called medium consistency processing);
- pre-drying of lime; and
- good process control.

Measures that the IPPC-BAT proposes for the low consumption of electric power include:

- higher pulp consistencies in screening and cleaning to reduce volume flow rates of water pulp suspensions;
- speed control of large motors (variable or adjustable speed drives);
- efficient vacuum pumps; and
- proper sizing of pipes, pumps and fans.

Measures that the IPPC-BAT proposes for high power generation include:

- high boiler steam pressures (and superheat temperature as well, though not mentioned);
- outlet steam pressure from back-pressure turbines as low technically feasible;
- condensing turbines for power production from excess steam;
- high turbine efficiency; and
- preheating of air and fuel charged to boilers.

[32] *Cumulative Impact Study for two recent Uruguayan pulp mills: Cumulative Impact Study – Uruguay Pulp Mills*, EcoMetrix Incorporated, Sept 2006. http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/$FILE/Uruguay_CIS_AnnexC_Oct2006.pdf

6.2.2 *Benchmarking some recent world class mills*

It is normal practice in benchmarking the energy used by kraft pulp mills that the steam and power used for onsite production of ClO_2 and oxygen be included as part of the energy accounting of bleached pulp production. However, other chemicals used in the process such as methanol, sulphuric acid, caustic soda / chlorine, sulphur dioxide as required, are not counted, that is, it is considered as off-site manufacture.

Energy benchmarking data is presented in Table 6.1 for the two mills in Uruguay. One of the Uruguayan mills is being constructed by Botnia and is expected to start up in 4th Q 2007 while the other is a mill proposed by Ence-CMB. The Gunns mill in Tasmania has recently received environmental approval and will probably start up in 2010. All the data in Table 6.1 are the design values and a consistent basis for comparison.

Table 6 1 - Steam and Power Use in Recent New Bleached Kraft Pulp Mill Designs

	Units	Gunns Bell Bay Tasmania	Botnia-Orion Uruguay	Ence-CMB Uruguay	European Commission BAT [c]
		Eucalypt	Eucalypt	Eucalypt	Hardwood
Production capacity	ADt[a]	3143	3000	1500	-
	ADt/a [b]	1 012 675	966 660	483 300	-
Steam for process and soot blowing	GJ/ADt	9.3(d)	9.8	10.5	10 - 14
Power for process	kWh/ADt	816	572	615	600-800

Notes:
a – Daily production capacity
b – Annual production = average daily production rate x x358 / 0.90
c – Best available techniques (BAT) which include design and operation, IPPC 2001-12
d - It is not clear whether soot blowing has been included in the steam use

APPENDIX A - Regulations and Management Measures

APPENDIX A - AIR EMISSION REGULATIONS AND MANAGEMENT MEASURES

A - 1 Introduction

This section provides an overview of the industry air emission regulatory process and emission limits for:

- the Canadian provinces of BC, Ontario and Quebec
- the United States
- The European Union, Finland, and Sweden; and
- The World Bank.

Brief mention should be made of a growing adoption of Environmental Management Systems (EMS)[33] across the global pulp and paper industry. An EMS, whether ISO 14000, British Standard (BS) 7750, or European Eco-Management and Audit Scheme (EMAS), is a structured program of procedures that lead toward continuous environmental improvements beyond the initial regulatory framework of limits and permits for pollution prevention. Built upon a similar structure to a quality management system, an EMS can benefit an enterprise commercially by enhancing free trade by its commitment to environmental improvement.

A - 2 Regulations in the Canadian Provinces of BC, Ontario and Quebec

A - 2.1 Federal and Provincial Regulatory Approaches

The federal government role in air emission regulation is focused on interprovincial and trans-boarder issues and international agreements dealing with air quality, ozone depletion and acid rain, since it is constrained by the British North America Act (BNA) of 1867 to not regulate within provincial boundaries. The BNA has been interpreted to impose on the federal government the obligation to lead in areas where a national coordinated approach is required such as in establishing guidelines and regulations.

[33] http://wbln0018.worldbank.org/essd/essd.nsf/GlobalView/PPAH/$File/23_iso.pdf

The most far-reaching and important Federal legislation in recent years was the promulgation of the Canadian Environmental Protection Act in 1988, and amended in 1999. This led to the establishment of a:

- Priority Substances List:
  - A review process to identify CEPA toxics released to the environment
  - Schedule 1 of the CEPA toxics list comprises 85 compounds with significant health and environmental consequences.
- National Pollutant Release Inventory
  - Annual reporting by major source emitters (for some: >10t/a, 1% concentration) of more than 250 compounds
- NOx VOC Management Plan
  - Coordinated by the Canadian Council of Ministers of the Environment (CCME) which produced Guidelines
  - Addresses tropospheric (low level) ozone and smog in problem areas such as the Windsor– Quebec Corridor and Lower Fraser Valley in BC.

A - 2.2 Provincial Regulatory Process

A - 2.2.1 General

The Provinces are mandated to protect public health and the environment but also react to public complaints. Based on a survey conducted in the late 90s[34], the priority drivers for provincial air regulators in order of descending importance were:

1. public health;
2. public complaints;
3. environment; and
4. best current practice technology and control performance.

For those Provinces with a significant pulp and paper industry such as BC, Ontario and Quebec, use three tools are used:

- Regulation;
- The issue of one or several authorizations such as permits, licences and construction approvals; and
- follow up compliance monitoring and enforcement.

Regulations define minimum requirement Province-wide and if called guidelines, objectives, or recommended requirements are less binding. Regulations apply to new or major modifications to existing, but are not normally retroactive, that is apply to existing facilities that have undergone no significant change.

Compliance Monitoring and Enforcement involves submission of source discharge data and may require periodic sampling by independent contractors.

[34] *Characterisation of Provincial Regulatory Framework for Air Emissions from the Pulp and Paper Industry*, by Simons Environmental Consultants (now AMEC) for Environment Canada, 1997

Most provincial governments regulate air emissions by permitting either maximum ground level concentrations as "Ambient Air Quality" limit values, or limits on the discharge of specific pollutants at the "End-of-Stack". The limits can be expressed as a concentration (mg/m^3, $\mu g/m^3$, ppm) or a mass limit (kg/h, kg/d, kg/unit of production). In the case of concentration-based limits the measured emission is corrected to the standard conditions of temperature, pressure, oxygen content and moisture specified in the regulations.

The end-of-stack approach limits the emission of a contaminant at the point of discharge which may be a stack or a vent. The ambient air limit is an average concentration not-to-be-exceeded in the ambient air typically measured at ground level. The maximum allowable concentration is averaged over a specified time period, usually 1 hour, 24 hours or a year. This approach considers the air quality within the air-shed rather than individual emissions at point sources.

Ontario and Newfoundland alone among the provinces use Point-of-Impingement (POI) method. This uses a simplified mathematical model of the stack plume dispersion that combines the effects of one or a group of point source emissions. The modelling determines the theoretical maximum concentration at one or more ground level locations designated as "critical receptors".

In a few specific cases control of a particular emission is technology based with mandated procedures or technologies. Technology-based controls are typically used in regulating the TRS emissions from different sources where the emission standard may be "incineration or equivalent" rather than a concentration or a mass limit.

Table A -1 summarizes the regulatory approaches used in the different provincial jurisdictions. All provinces have ambient air quality limits whether called a guideline, criteria, objective or a regulated limit, depending on the province, with the qualifiers suggesting the degree of flexibility.

Table A - 1: Approach to Air Emission Regulations

Approach/Province	AB	BC	ON	QC
Ambient Air	√	√	√	√
End-of-Stack	√	√		√
Point-of-Impingement			√	

A - 2.2.2 Contaminants of interest

The original focus of air emission regulation was on the control of odour and dust affecting the air quality of the local community. Controls of acidic gases contributing to acid rain, fine particulate ($PM_{2.5}$), ozone and other hazardous air pollutants (HAP) have been added to the objectives for air emission regulation over the years.

The principal contaminants in ambient air guidelines relevant to the pulp and paper Industry are summarized by province in Table A - 2. Some provinces have guidelines for many additional substances, which are either not relevant to the pulp and paper operations or are only occasionally present in minor quantities compared to compounds in Table A - 2.

Table A - 2: Ambient Air and Point-of-Impingement Guidelines

Contaminant/Province	AB	BC	ON	QC
H_2S and TRS	√	√	√	√
NO_x	√		√	√
SO_x or SO_2	√	√	√	√
Particulate Matter (PM)	√	√	√	
Fine Particulate Matter (PM_{10} or $PM_{2.5}$)	√	√	√	√
Carbon Monoxide (CO)	√	√	√	√
Ozone	√		√	√
Chlorine (Cl_2)			√	
Chlorine Dioxide (ClO_2)			√	

In general, the provincial regulatory framework comprises a three-step approach that starts with the environmental acts of the respective jurisdictions to provide the legal basis for regulation. The second step involves specific environmental regulations promulgated under the act or acts to impose specific air emission limits. The third step is the issuing of licenses or permits to individuals and organizations that permit the construction and operation of facilities following technical submissions that demonstrate the proposed facilities are being appropriately designed and the planned methods of operation are consistent with complying with the regulations.

Some acts and regulations are specific to the pulp and paper sector while others may be general or apply to activities common to pulp and paper operations such as power generation.

Regulated emission limits will differ based on factors such as whether the new facilities:

- Are on a greenfield site or the upgrade of existing facilities;
- Are located in an urban or rural location; and
- Represent a significant change in size or production capacity.

Some provinces impose expiry dates for permits; others do not as shown in Table B - 3.

Table A - 3: Duration of Permit Validity

Province	Permit Validity
Alberta	up to 10 years
British Columbia	does not expire
Manitoba	does not expire
New Brunswick	up to 5 years
Nova Scotia	10 years
Quebec	5 years
Saskatchewan	1-2 years

In Ontario, the Ministry may request a demonstration of compliance at any time.

Circumstances that might trigger the permitting process include:

- a permit expiry;
- the installation of new equipment;
- a modification of the process;
- a change in production rate; and
- at the discretion of the Ministry.

A - 2.3 British Columbia

The *Environment Management Act* (BC EMA) was created in 2004 to combine the former *Waste Management Act* introduced in 1982 and the *Environment Management Act* into a single statute. The new BC EMA contains changes that allow ministry resources to be focused on higher risk discharges and enables low to medium risk discharges to be regulated by province wide codes of practice. Prior to 1982, discharges were regulated under the Pollution Control Act of 1967.

Pulp and paper mills continue to be subject to mill-specific air permits because of the high level of environmental risk their discharges represent, given the mountainous terrain many mills are located. An issued permit legitimizes the discharge of waste within the terms of the permit. Only industries specified in the Act, which include pulp and paper operations have formal authority to discharge waste into the environment. The permits are not yet single integrated pollution prevention and management documents covering air, water and solid waste discharges as is the case in some other jurisdictions.

The BC EMA provides the regulation of discharges to air, water and land and a permit issuing, discharge reporting, approval and compliance function, and the process has not significantly changed with the introduction of the new Act. Environmental management in BC is

decentralized for purposes of administering the Act. The BC Ministry of Environment (BCMOE) regional offices under the direction of a Regional Environmental Protection Manager administer permits and regulations, while the BCMOE head office develops regulations, objectives and policies. The legislation gives the regional manager the power to decide the terms of a permit who has traditionally used information obtained from many other jurisdictions with significant pulp and paper industries. The permit conditions are established in consultation with pulp mill technical staff by each individual region and the regional manager has final authority on the content and issuing of the permit. Permit conditions are established that will protect the environment and ensure normal fluctuations of emission quality under good operating conditions do not exceed the permit standard. This "margin of safety" allows reasonable flexibility for the mill operator while protecting the environment[35]. BC EMA does not require installation of best available current control technology.

There have been two major policy documents in BC that have assisted industry and regulatory decision makers by providing guidelines or objectives for the control of air emissions from pulp mills. The first of these were the *Pollution Control Objectives for the Forest Products Industry of British Columbia* which were introduced in 1974 and set limits on air discharges. These Objectives contain both ambient air quality objectives and end-of-stack limits; Level A applying to new / modernized facilities; and Level B to existing facilities. These *Objectives* had no legal authority but in the past were followed quite closely when establishing permit conditions. These were revised subsequently in 1977, and reflected 1970s pulping and emission control technology.

On November 16, 1993, BC introduced a '*A Draft Policy on the Development and Application of Waste Discharge Criteria Based on Best Available Control Technology'* prepared by the Ministry of Environment, Lands and Parks which proposed that waste discharge criteria be based on a number of considerations that include, among other things, the emission levels attainable by Best Available Control Technology (BACT) as "a technology that has been proven successful and used under similar conditions in the province or other comparable jurisdiction over a period of at least one year". This prompted the Ministry to contract H. A. Simons Ltd to prepare a background report establishing the basis for BC BACT[36]. Following a technology review, the BC Ministry of Environment Lands and Parks (now the BC MOE) Pulp Mill Emission Technical Committee issued a *Technical Memo on Pulp Mill Emissions* in draft form 10 November 1995 to update end-of-stack emission guidelines. The Memo which went out to regional managers was to assist them in setting permit limits for pulp mills installing new facilities or major upgrades. The document has not been issued in final form and should be seen as a guide to aid Regional Managers and not official policy.

To explore possible next steps the BC Ministry of Environment funded a study titled *Kraft Pulp Mill Emission Guidelines and Standards / Pre-scoping Final Report / A Jurisdictional Review,* issued in March 2007 that compares the emission limit values of the most recently issued BC mill permits with standards of other jurisdictions.

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[35] BC Ministry of Environment, *Kraft Pulp Mill Emission Guidelines and Standards / Pre-scoping Final Report / A Jurisdictional Review*, March 2007, by Crozier Consulting and Services, Nelson, BC in association with Ron A. Bollans, Nanimo.

[36] *A Technical Background Information Document on the Pulp and Paper Mill Air Emissions,* for the BC Ministry of Envrionment, Lands and Parks and Envionment Canada, by H.A. Simons Ltd. (Vancouver), Norecol Dames & Moore (Vancouver), and AFIPK (Stockholm), principal author Douglas. M. Bruce, Oct 1994, Revised April 1995

Since permits have no expiry date, the technical memo on pulp mill emissions guidelines do not apply to existing mills. However, an amended permit is required for a significant change in production rate, installation of new equipment, modification of process or at the discretion of the regional manager. Permits contain end-of-stack emissions and ambient limits, stack and ambient monitoring requirements, as well as upgrading and construction requirements, if applicable. All significant sources of air emissions including stacks, vents, and exhausts and their associated emission control equipment are listed in the single permit document.

BC charges a fee for a permit application and has annual discharge fees based on the amount allowed in the permit limit. Permit applications are advertised in local newspapers and public comments are invited. The permits can be appealed by the company or by concerned individuals.

Currently, provincial regulations limit the sulphur content of fossil fuels to a maximum of 1.1%.

A - 2.4 Ontario

The Environmental Protection Act of 1990 is the main act that governs environmental rules and regulations in Ontario. The Act prohibits discharge of any contaminant into the environment in amounts, or concentrations or levels exceeding those prescribed by the regulation.

The Air Pollution Regulation of 1990 uses a point of impingement concept which sets enforceable ambient air quality standards for concentrations for 87 different contaminants, eight of which particularly relate to pulp and paper operations. The limits are based on half hour time averaged concentrations. The standards are applied where computer dispersion models indicate maximum ground level concentrations for a group of emission sources.

In addition, Ontario in 2005 enacted two regulations that require industry to further reduce air emissions of harmful emissions related to acid rain and smog. These are:

- Regulation 194/05 Industry Emissions - Nitrogen Oxides and Sulphur Dioxide which came into effect on January 1 2005 and is focused on reducing industry sources and is projected to reduce NOx by 21% and SO_2 by 46% by 2015; and

- Regulation 419/05 Air Pollution - Local Air Quality[37], replacing Regulation 346, which came into effect on November 30 2005, which sets province-wide point of impingement ambient air quality limits that become more restrictive over time and all the existing pulp and paper mills having to meet these more restrictive standards and use US EPA dispersion models by the year 2013.

In addition the Regulation 194 introduces a plant-wide emission intensity limit on NOx and SOx (t/ADt) for each existing kraft pulp mill that in some cases become more restrictive over time, the most restrictive reached in 2010. For NOx, reductions range from zero to 30%, and for SOx from zero to 57%.

[37] Regulation 419/05 Air Pollution - Local Air Quality at http://www.ene.gov.on.ca/envision/air/regulations/localquality.htm

A further requirement of Regulation 194 is the need to install Best Available Control Technology Economically Achievable (BACTEA) if:

- A new facilities produces more than100,000 ADt/a, or
- A new or modified process at a facility involves equipment with a heat input of 1 million Btu/h or more, or
- Annual production will increase by 20% over historical levels.

For further details the reader is referred to a recent report by Crozier[38].

It is important to note that to quantify the amount of mill emission source reduction needed to meet the more restrictive ambient air quality standards under Regulation 419 is essentially impossible without running scenarios using a sophisticated air dispersion modeling program given the large number of inputs, such as low elevation and higher elevation (stack) emission source strengths and discharge characteristics.

Ontario's BACTEA is a top down technology evaluation process similar to that required by the US EPA's Prevention of Significant Deterioration Program to be described in a later section. Ontario's BACTEA policy allows flexibility to choose lower cost control technology alternatives so long as removal efficiency is within 15% of the highest control efficiency.

The Boilers Regulation of 1990 limits the sulphur content of fossil fuels to a maximum of 1%.

In 1990, Interim Design and Review Guidelines were introduced for wood-fired boilers and heaters limiting discharge concentrations of particulate matter and a requirement to monitor combustion temperature. In addition, the Regulation requires the maintenance of a minimum combustion temperature and excess oxygen content of 6% by volume dry basis in the flue gas. A minimum residence time of one second has to be demonstrated.

The requirements are summarized in Table A - 4.

Table A - 4: Ontario Interim Design and Review Guideline for Wood-fired Combustors - Clean Wood Only (Draft Proposed 30 Aug 1990)

Size of Unit	Particulate Limit	Temperature, Retention time and Oxygen Content
<200t/d as fired	90 mg/m^3	1000°C, 1 sec., 6% O_2 by volume
>200t/d as fired	50 mg/m^3	1000°C, 1 sec., 6% O_2 by volume

In the foregoing table the standard conditions of the concentration limit are not specified.

[38] BC Ministry of Environment, *Kraft Pulp Mill Emission Guidelines and Standards / Pre-scoping Final Report / A Jurisdictional Review*, March 2007, by Crozier Consulting and Services, Nelson, BC in association with Ron A. Bollans, Nanimo.

Approval System

The Environmental Protection Act states that a Certificate-of-Approval (C-of-A) is required to construct or alter any equipment that may discharge a contaminant into the environment. Construction approvals are required for the installation or modification of equipment that release air contaminants into the environment Approvals typically do not encompass whole facilities. Older equipment may not have approvals if installed prior to 1963. A typical kraft pulp and paper mill may have up to 25 approvals for various pieces of equipment.

A new approval is required for each new piece of equipment, either for emission control equipment or for a process which has associated emissions. Occasionally, if a mill requests a new approval, the MOE may require the mill to control other sources before delivering the approval.

A new or amended approval is also required for a change in production rate, modification of process or at the discretion of the ministry. Approvals are not renewed on a regular basis and are usually valid until the equipment is modified.

All air approvals are issued from the Ministry of the Environment head office. Approvals in the pulp and paper industry generally do not contain any type of discharge limit for air emissions requirements, but any commitments (i.e. design specifications) made by the applicant are legally binding. A proponent must meet all applicable regulations, guidelines and policies.

Approval applications are advertised on a public registry (Environmental Bill of Rights or EBR) for 30 days and the public is invited to comment. Approvals can be appealed.

Control Orders

The Ministry of the Environment can issue a Control Order if the contaminant contravenes the regulations or is causing an adverse effect. Through a Control Order the Ministry of the Environment may require the mill to:

- limit, control or stop the rate of discharge of the contaminant;
- install or replace any equipment used to control or eliminate the discharge; and,
- study and report on measures to control the discharge, the receiving environment and its effects on the receiving environment.

Ontario charges a fee for a permit application but has no annual or discharge fee.

A - 2.5 Quebec

The Environmental Quality Act of 1972 is the main legislation that governs environmental matters in Quebec. There are numerous regulations under the Act that deal specifically with air quality and air discharges.

Quality of the Atmosphere Regulation of 1979 sets discharge limits for fossil fuel combustion, hog fuel combustion, incinerators, and various industry-specific limits. Air emissions are normalised to 25°C and a pressure of 101.325 kPa.

On 7 October 1992, a Pulp and Paper Mills Regulation, was published setting limits for air, water and solid waste for pulp and paper mills that came into effect on 22 October 1992 for new mills and for new mills operating before 22 October 1992, came into effect on 31 December 1996. The regulations set discharge limits for kraft and sulphite mill sources include the recovery boiler, lime kiln, smelt dissolving tank vents as well as NCGs from the digester system, evaporator system, brownstock washers system and the condensate stripper system.

The Quebec Minister of Sustainable Development, Environment and Parks / Ministere de Development Durable, Environnement et Parcs (MDDEP) has for some years been working on changes to the Quality of the Atmosphere Regulation, and the technical aspects have been issued in draft form on 15 November 2005. The main changes for the pulp and paper industry include a reduced particulate limit for wood waste boilers. The regulation is to be officially published by the end of 2007. The limits in the draft have been used in the comparison tables that follow.

The Environmental Quality Act required an approval to discharge a contaminant to the environment for new and modified sources. If a source existed before 1972 and has never been modified, then it is grandfathered. Each air emission source required an approval. The approval did not contain end-of-stack limits or monitoring requirements, but any document submitted by the applicant must, at least, insure compliance with regulatory limits; additions are legally binding. Approvals are issued from the MDDEP regional offices and the regional director had final authority in issuing the approval. There is no public advertising for approval applications but approvals can be appealed.

The approval system was modified in1993 by the introduction of the Industrial Depollution Attestation Regulation requiring all pulp and paper mills to apply for a Depollution Attestation, which corresponds to a permit in other jurisdictions.

The approval system of the Environmental Quality Act will stay in force for major projects involving significant capacity increase, or major modernizations. The Depollution Attestation includes all regulatory requirements with regard to air, water, and land. The Depollution Attestation may have more stringent end-of-stack limits and monitoring requirements based on the requirement of the receiving environment considerations. The Depollution Attestation are prepared jointly by the central administration and regional offices and issued by the MDDEP head office. Each mill requires a Depollution Attestation to operate which is valid for five years.

Quebec charges a fee for a Depollution Attestation application, an annual fee and a discharge fee based on the amounts of contaminants discharged.

Provincial regulations limit the sulphur content of fossil fuels to a maximum of 2.0% until March 2006, and then 1.5% thereafter throughout Quebec.

A - 2.6 Comparison of AB, BC, ON and QC limits

A summary of the provincial end-of-stack requirements is presented in Tables A - 5 through A - 9. Where Alberta Environment limits exist or are proposed, these are included as well. The limit values are shown at the standard and reference conditions of the regulation or permit. Any particular mill might have a more stringent limit than that listed because of site-specific conditions. Therefore these provincial emission limits cannot be numerically compared directly as standard conditions and reference flue gas oxygen or carbon dioxide contents, or the standard temperature conditions may differ.

Table A - 5: TRS Emission Limits for New Sources

Source	AB [a]	BC [b]	QC
Recovery boiler	6.5 ppm_{DV} (4 h)	7 ppm_{DV} (1 h) 3 ppm_{DV} (24 h)	5 ppm_{DV}
Lime kiln	10 ppm_{DV} (4 h)	8 ppm_{DV}	10 ppm_{DV}
Smelt tank	16 g/t of BLS	8.4 g/t of BLS	16 g/t of BLS
Digester relief system	-	Incinerate or Equivalent	10 ppm_{DV}
Digester blow system	-	Incinerate or Equivalent	10 ppm_{DV}
Evaporators [a]	-	Incinerate or Equivalent	10 ppm_{DV}
Condensate stripper	-	INCINERATE OR EQUIVALENT	10 ppm_{DV}
Brown stock washers [a]	-	-	10 ppm_{DV}

Notes: a - Informal Standard believed to be from the early 1990s

Table A - 6: TRS Emission Limits for Existing Sources

Source	AB	BC	QC
Recovery boiler	6.5 ppm_{DV}	26 ppm	20 ppm_{DV}
Lime kiln	10 ppm_{DV}	0.225 kg/ADt	10 ppm_{DV}
Smelt tank	0.9-4.0 kg/h	0.225 kg/ADt	-
Digester relief system	Incinerate or Equivalent	Incinerate or Equivalent	10 ppm_{DV}
Digester blow system	INCINERATE OR EQUIVALENT	Incinerate or Equivalent	10 ppm_{DV}
Evaporaters [a]	Incinerate or Equivalent	Incinerate or Equivalent	10 ppm_{DV}
Condensate stripper	Incinerate or Equivalent	Incinerate or Equivalent	10 ppm_{DV}
Brown stock washers [a]	Incinerate or Equivalent	-	10 ppm_{DV}

Note
a - In Quebec, the limit applies to the complete evaporator system and brownstock washer system.

Table A - 7: Particulate Emission Limits for New Sources

Source	AB - former [a]	AB - proposed [b]	BC[c]	ON[39]	QC
Recovery boiler @8% O_2 by vol.	100 mg/$S_{25}Dm^3$	34mg/$S_{20}Dm^3$	50 mg/$S_{20}Dm^3$	-	100 mg/$S_{25}Dm^3$ (e)
Lime kiln @10% O_2 by vol.	150 mg/ $S_{25}Dm^3$	23mg/$S_{20}Dm^3$	80 mg/$S_{20}Dm^3$	-	150 mg/$S_{25}Dm^3$ (e)
Smelt tank	100 g/t BLS	60 g/t BLS	60 g/t BLS	-	100 g/t BLS
Boilers - Hog fuel (d)	100 mg/ $S_{25}Dm^3$ @8% O_2 by vol.	0.025lb/MBtu (≈ 28mg/$S_{20}Dm^3$ @7% O_2 by vol.)	50 mg/$S_{20}Dm^3$ @8% O_2 by vol	90 mg/SDm^3 %O_2 not specified	>3-10MW 340mg/$S_{25}Dm^3$ (f) >10MW 70 mg/$S_{25}Dm^3$ (f)
○ pulp and paper mill waste			-		>3MW 70 mg/$S_{25}Dm^3$ (f)
Boilers - Fossil Fuel					
○ Oil	-	-	-	-	>3-15MW 60g/GJ >15MW 45g/GJ
○ Coal, coke	-	-	-	-	>3-70MW 60g/GJ >70 MW 45g/GJ

Notes
a - Informal Standard believed to be from the early 1990s
b - As proposed in Alberta Environment's draft Rationale Document of in the spring of 2006. Based on US MACT regulations.
c - Recommended permit requirements for new facilities and facilities undergoing major modification, British Columbia, Ministry of Environment, Lands and Parks, Technical Memo – Pulp Mill Emission Technical Committee, Draft 10 November 1995.
d - Bark, wood and wood waste.
e - Corrected to 8% O_2 by volume dry basis
f - Corrected to 7% O_2 by volume dry basis. Proposed limit in the Gouvernment du Quebec, Ministere de l'environnement, *Projet de reglement modifiant le regelement sur la qualite de l'atmosphere (R.20).* 12 June 2000 for units > 10 $MW_{thermal}$, otherwise 340 mg/Nm^3. Confirmed 2007-10-11 Andre Grondin, MDDEP, 418-521-3950=4072..

[39] Ontario Guideline for wood waste combustors

Table A - 8: Particulate Emission Limits for Existing Sources

Source	AB	BC	QC
Recovery boiler	0.2 g/kg of flue gas (≈ 332mg/$S_{25}Dm^3$ - see (d))	11.0 mg/mol	200 mg/$S_{25}Dm^3$ (c)
Lime kiln	0.2 g/kg of flue gas	11.0 mg/mol	340 mg/$S_{25}Dm^3$ (c)
Smelt tank	-	0.40 kg/ADt	165 g/t BLS
Boilers - Hog fuel [b]	0.2 - 0.6 g/kg of flue gas (≈ 306mg/$S_{25}Dm^3$ - see (e))	50 mg/$S_{20}Dm^3$	>3-10MW 340 mg/$S_{25}Dm^3$ (c) >10MW 100 mg/m^3 (c)
pulp and paper mill waste	-	-	>3MW 100 mg/$S_{25}Dm^3$ (c)
Boilers-Fossil fuel			
○ Oil	0.2 g/kg of flue gas	-	>3-15MW 85g/GJ >15MW 60g/GJ
○ Coal, coke			>3-70MW 85g/GJ >70 MW 60g/GJ

Notes
a - Corrected to 7% O_2 by volume dry basis. Proposed limit in the Gouvernment du Quebec, Ministere de l'environnement, *Projet de reglement modifiant le regelement sur la qualite de l'atmosphere (R.20).* 12 June 2000 for units > 10 $MW_{thermal}$, otherwise 340 mg/$S_{25}Dm^3$. Confirmed 2007-10-11 Andre Grondin, MDDEP (Qebec Ministry of Environment), 418-521-3950=4072.
b - Bark, wood and wood waste.
c - Corrected to 8% O_2 by volume dry basis.
d - Which, assuming wet flue gas, is approximately 332mg/$S_{25}Dm^3$ for liquor at 70% and excess O_2 of 3% by volume dry basis.
e - Which, assuming wet flue gas, is equivalent to approximately 306mg/$S_{25}Dm^3$ for wood moisture content of 50% and excess O_2 of 7% by volume dry basis.

British Columbia, Ontario and Quebec have opacity regulations in addition to the particulate standards for emissions from existing boilers. British Columbia limits power boiler opacity to a maximum of 20% allowing a maximum of 40% average for 2h /d during grate cleaning. Ontario and Quebec limit opacity to 20%.

Table A - 9: Boiler Regulations NOx and SO_2

Source	SO_2	NOx			
	BC	AB	BC[e]	ON	QC
Recovery boiler	50 ppm_{DV} (24 h) 150 ppm_{DV} (1 h)	-	125 ppm_{DV} (1 h)	-	-
Lime kiln	-	-	[f]	-	-
Boilers - Hog	-	258g/GJ	125 ppm_{DV}(1 h)	-	-
Boilers – New					
Gas	-	-	-	26/40 g/GJ[d]	26/40 g/GJ [b]
Distillate [a]	-	-	-	40/50 g/GJ[d]	40/50 g/GJ [b]
Heavy Oil [a]	-	-	-	110/125 g/GJ[d]	90/90 g/GJ [b, g]
Coal [a] " – Existing	-	-	-	-	-
Gas					
Distillate [a]	-	-	-	-	80/110 g/GJ [c]
Heavy Oil [a]	-	-	-	-	175/135 g/GJ [c]
Coal [a]	-	-	-	-	260/290 g/GJ [c]
	-	-	-	-	-

Notes
a - Fuel limited to 1.1% sulphur in BC, and also limited in sulphur content in some other provinces as well.
b - First figure/second figure designates gross heat input range of ≥3-≤30 GJ/h / >30 GJ/h.
c - First figure/second figure designates gross heat input range of ≥15-≤70 GJ/h / >70 GJ/h.
d - First figure/second figure designates boiler capacities >10.5-≤105 GJ/h/>105 GJ/h.
e - Recommended permit requirements for new facilities and facilities undergoing major modification, British Columbia, Ministry of Environment, Lands and Parks, Technical Memo – Pulp Mill Emission Technical Committee, Draft 10 November 1995.
f - "…the use of combustion control technology such as Low NO_x Burners to reduce NO_x emissions should be required."
g - For fuel nitrogen content <0.35% w/w, otherwise for ≥3-≤30 GJ/h limit of 110g/GJ, >30 limit of 125g/GJ.

Provincial ambient air criteria are summarized in Table A -10. These criteria represent the acceptable ambient air quality in the individual provinces.

Ontario and Newfoundland also use the POI concept to regulate air emissions. Table A - 11 summarizes maximum ground level concentrations for both provinces. Newfoundland uses a one hour averaging period and Ontario uses a 30-minute averaging period. POI limits cannot be directly compared to one another if the averaging periods are different.

The Environment Canada and Health Canada ambient air objectives are shown in Table A -12. The federal objectives use three classifications of air quality; *desirable*, *acceptable* and *tolerable*. *Desirable* is the long-term goal for air quality, '*acceptable*' is intended to provide adequate protection, and '*tolerable*' represents the upper limit beyond which appropriate action is required to protect the health of the general population.

Table A - 10: Provincial Ambient Air Criteria ($\mu g/m^3$)

Contaminant		AB	BC	ON	QC
H_2S/TRS					
	1 hour	14	7	30	6
	24 hour	4	3	-	-
NO_X / NO_2					
	1 hour	400	400	400	414
	24 hour	200	200	200	207
	Annual	60	100	-	103
SO_2					
	1 hour	450	450	690	900
	24 hour	150	160	275	300
	Annual	30	25	55	60
PM					
	24 hour	100	150	120	-
	Annual	60	60	60	-
Fine Particulate:					
PM_{10}	24 hour	-	50	-	-
$PM_{2.5}$	1 hour	80 (a)	-	30	30
	24 hour	30 (a)	-	-	-
CO					
	1 hour	15 000	14 300	36 200	34 000
	8 hour	6000	5500	15 700	12 700
	24 hour	-	-	-	-
Ozone					
	1 hour	160(a)	-	165	157
	24 hour	50	-	-	-
	Annual	-	-	-	-

Note: a - Alberta Air Quality Objective effective 1 Feb 2007.

Table A - 11: POI Regulated Limits

Contaminant	Ontario ($\mu g/m^3$) (half-hour average)	Newfoundland ($\mu g/m^3$) (one hour average)
H_2S	30	25
PM	100	80
SO_2	830	680
NO_x	500	400
CO	6000	5000
Cl_2	300	250
ClO_2	85	70

Table A - 12: Federal Ambient Air Objectives ($\mu g/m^3$)

	Desirable	Acceptable	Tolerable
H_2S			
1 hour	-	-	-
24 hour	-	-	-
NO_2			
1 hour	-	400	1000
24 hour	-	200	300
Annual	60	100	-
SO_2			
1 hour	450	900	-
24 hour	150	300	800
Annual	30	60	-
PM			
24 hour	-	120	400
Annual	60	70	-
CO			
1 hour	15000	35000	-
8 hour	6000	15000	20000
24 hour	-	-	-
Ozone			
1 hour	100	160	300
24 hour	30	50	-
Annual	-	30	-

Table A -13 presents Canada-Wide Standards developed for ozone and fine particulate matter and subsequently endorsed by the Canadian Council of Ministers of the Environment Council of Ministers (CCME) 4 - 6 June, 2000 in Quebec City.

Table A - 13: Canada Wide Standards for Ozone and $PM_{2.5}$

Contaminant	Averaging Time	Limit
$PM_{2.5}$ (Achievement to be based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.)	24 hours	$30\mu g/m^3$
Ozone (Achievement to be based on the 4th highest measurement annually, averaged over 3 consecutive years.)	8 hours	65ppb

A - 2.7 Kraft Mill Odour Abatement Requirements in Selected Provinces

Alberta

Alberta Environment requires all kraft mills to collect and dispose of both CNCG and DNCG emissions and must include a secondary treatment point. The Alberta Environment also limits the number of hours per month that a mill is allowed to vent NCG emissions to the atmosphere.

British Columbia

A BC MOE draft technical memo[40] on pulp mill emissions recommends that all CNCG sources and DNCG sources with a concentration of 5 ppm_{DV} or more be collected and treated. The memo also recommends that a secondary treatment point be installed to treat the CNCGs. Venting NCG is allowable only under emergency situations. The draft technical memo is not considered as policy at this time but as a guide for regional managers in determining permit requirements. Some individual permits include conditions that limit venting which were not the result of mill upgrades, but were to address regional air quality concerns and are permit-specific.

Ontario

The Ontario MOE regulates both ambient air and POI concentration of H_2S thus indirectly requiring mill to collect and treat CNCG and possibly DNCG sources as well. The MOE does not directly require mills to collect CNCG nor DNCG sources, however the MOE would likely require this for new or modernizing mills when the proponent seeks a Certificate of Approval.

Quebec

The pulp and paper regulation states the CNCG and DNCG sources and brownstock washer emissions must not be emitted to the atmosphere with a TRS concentration exceeding 10 ppm_{DV}. The Quebec MOE does not specifically state that a collection and incineration system be installed for either CNCG or DNCG, though this is implied in order to meet the 10 ppm_{DV} limit, since dilution with additional air is not permitted.

[40] Recommended permit requirements for new facilities and facilities undergoing major modification, British Columbia, Ministry of Environment, Lands and Parks, Technical Memo – Pulp Mill Emission Technical Committee, Draft, 10 November 1995.

Table A - 14: CNCG Requirements for Existing Mills

Province	Collection Required	Primary Disposal	Secondary Disposal	Limitations on Atmospheric Venting
AB	Yes	Yes	yes	yes
BC	Yes	Yes	when upgrading	when upgrading
ON[41]	No	No	no	no
QC[42]	Yes[43]	No	no	no

Table A - 15: DNCG Requirements for Existing Mills

Province	Collection Required	Primary Disposal	Secondary Disposal	Limitation on Atmospheric Venting
AB	Yes	Yes	yes	yes
BC	Yes[44]	Yes	no	no
ON [41]	No	No	no	no
QC	Yes[45]	No	no	no

A - 3 Regulations in the US

A - 3.1 Regulatory Approach

The federal Clean Air Act (CAA) and its amendments (CAAA) are the legislative authority that assigns the US EPA its role in implementing air-related environmental regulations and permitting systems. There are six principal parts or sections called "Titles"[46] that:

- establish National Air Ambient Quality Standards (NAAQS);
- stipulate that states have a State Implementation Plan (SIP);
- set uniform national standards called New Source Performance Standards (NSPS);
- set National Emission Standards for Hazardous Air Pollutants (NESHAP);
- develop guidelines for mobile sources; and
- address acid rain by reducing SO_2 emission allowances.

Permitting is delegated to state authorities or regional EPA district offices.
When the Clean Air Act was introduced in 1970, it did not include specific federal emission limits for kraft pulp mills. However, in 1978 the US Environmental Protection Agency

[41] The Ontario MOE regulates both ambient air and POI concentration of H_2S thus indirectly requiring mill to collect and treat selected NCG sources. Additional NCG requirement can be required by the MOE when a mill is seeking a new C-of-A or by control orders.
[42] Quebec limits the TRS concentration at 10 ppm for emissions from specific NCG sources.
[43] MEF emission limits (10 ppm) implies the collection and relatively complete treatment of all system sources which must comply with the 10 ppm limit.
[44] The BC MOE is in the process of requiring that existing mills collect and treat DNCG sources.
[45] MEF emission limits (10 ppm) implies the collection and relatively complete treatment of all system sources which must comply with the 10 ppm limit.
[46] http://es.epa.gov/oeca/sector/sectornote/pdf/pulppasn.pdf

promulgated New Source Performance Standards (NSPS) for kraft pulp mills. The federal NSPS established emission limits for PM and TRS compounds from the significant kraft pulping process units. These limits are for individual process units, but not the mill as a whole, such as in a kg/ADt basis; also the limits exclude the effluent treatment system. Emissions of SO_2 and NO_x were not to be regulated under the NSPS for kraft pulp mills and this continues to be the case. However, NO_x, PM, and SO_2 for wood, oil and natural gas fired industrial boilers are regulated under NSPS, and kraft recovery boilers continue to be excluded.

The 1977 Amendments of the Clean Air Act prohibits construction of a major stationary source or a major modification in an area subject to the Prevention of Significant Deterioration (PSD) regulations unless the emission source meets Best Available Control Technology (BACT) requirements. Sources subject to PSD are those located in areas of moderate to good air quality and outside regions designated as non-attainment areas, that is, where air quality does not meet federal ambient air quality standards. The objective was to minimize the impact of new industrial sources on the ambient air quality in areas where air quality was meeting national standards.

As mandated by Title III of the 1990 Clean Air Act Amendments, US EPA has developed hazardous air pollutant emission (HAP) standards for the pulp and paper industry that require process discharges to use Maximum Achievable Control Technology (MACT). Existing sources must meet MACT emission requirements and new sources must match or improve upon these requirements.

The MACT I standard for chemical pulp mills was included with the effluent guidelines when published in the Federal Register in December 1993. Together they are titled "the Cluster Rule" because the regulatory approach integrates both the air and the effluent rulemaking.

A - 3.2 Permitting Process

The Clean Air Act Amendments of 1977 allow no construction of a major stationary source, or a major modification, in an area subject to Prevention of Significant Deterioration (PSD) requirements unless the emissions source uses Best Available Control Technology or BACT. Federal regulations require BACT only for PSD sources, e.g., sources located outside air quality non-attainment areas, that is, in areas of moderate to good air quality, which trigger specified threshold criteria. Many states have not adopted criteria more stringent than the federal standards, although allowed to do so by regulation.

Establishing whether or not a PSD permit is required for a given project at a pulp and paper mill can be extremely difficult. As well there are many requirements in filing for a pre-construction PSD permit that can be very time consuming, such as acquiring ambient air monitoring data[47].

US EPA's "top-down" emission control evaluation process specifies that for a given source and contaminant all available control technologies be ranked in descending order of control effectiveness. The most stringent, or "top" alternative is examined first. That alternative is

[47] pg 1-13, NCASI Environmental Resource Handbook for Pulp and Paper Mills, National Council of Air and Stream Improvement Inc., Revised 31 Dec 2004.

established as BACT unless it is demonstrated that technical considerations, or energy, or environmental, or economic impacts justify a conclusion that the most stringent technology is not "achievable" in that case. If the most stringent technology is eliminated in this fashion, then the next most stringent alternative is considered, and so on.

There are five key steps in performing the BACT analysis:

1. Identify all control technologies;
2. Eliminate technically infeasible options;
3. Rank remaining control technologies by control performance;
4. Evaluate most cost effective controls and document results; and
5. Select BACT. NSPS is the baseline for BACT; in no event can emissions of any pollutants be in excess of the emissions allowed by any applicable NSPS.

In essence, therefore, BACT is determined for each emission source on a case-by-case basis by the permitting authority.

Federal PSD regulations specify that for new kraft pulp mill sources, the threshold triggering PSD review is 100 short tons per year of any criteria pollutant from a source or group of sources under common control, i.e. a mill site. For other types of new sources, such as mechanical mills and sulphite pulp mills, the threshold criterion is 250 short tons per year. The thresholds for major modifications are also defined by the PSD regulations; the thresholds are pollutant specific, e.g., the threshold for CO is greater that for NO_X. The major modification threshold levels were set by the US EPA based on modeling analyses performed by the Agency which considered control technology and acceptable level of impact for each pollutant. In no instances were the major modification levels set higher than 100 short tons per year, i.e. the threshold level for a new source in one of the 28 listed source categories. The PSD significant emission rates are shown in Table A - 16.

Table A - 16: PSD Significant Emission Rates

Emission	Significant Emission Rate in short tons per year
CO	100
NO_x	40
SO_2	40
TRS	10
TSP	25
PM_{10}	15
VOCs	40

If the appropriate PSD threshold 'Significant Emissions Rate' criterion is exceeded for any one regulated pollutant, then emissions of other regulated pollutants that do not exceed specified significant emission rates are also subject to PSD review and BACT requirements. The significant emission rates are also the threshold criteria used to determine the applicability of PSD review and BACT for major modifications.

For facilities located in air quality non-attainment areas, the New Source Review[48] is the applicable guideline. Because the ambient air quality is below the national standards for an area, the facilities having new sources and modifications must comply with the Lowest Achievable Emission Rate (LAER), a more stringent requirement than BACT. The emission rate is to reflect the most stringent emission limitation contained in any State Implementation Plan (SIP) for a source category or the most stringent emission limitation achieved by a source in the source category, whichever is more stringent. LAER does not take economic factors into account.

In addition, sources locating in these areas must purchase offsets for pollutants emitted by the facility for which the area is classified as non-attainment. Offsets are defined as an equivalent or greater emission reduction obtained from another source. The offsets provide one mechanism whereby the emission load to an air shed may be reduced.

Title V of the Federal Clean Air Act Amendments of 1990 established a national air pollution emission source permit program applicable to all new and existing major sources. Permits require renewal after 5 years. The definition of major sources are a source or group of sources under common control, such as a mill site, that has the potential to emit 100 short tons per year or more of any criteria pollutant, 10 short tons per year of any hazardous air pollutant (HAP) or 25 short tons per year of any combination of HAPs. Existing sources will not be subject to more stringent emission limits under Title V, but will be subject to more frequent monitoring and reporting than previously required and will have to demonstrate, through a federally enforceable method, that they are in compliance with all applicable regulations and permit conditions.

If a mill is not subject to Title V of the Federal Clean Air Act Amendments of 1990, some states with an operating permit program for non-major sources may require permit renewal after 10 years.

The BACT/LAER Information System (BLIS) is an electronic database clearinghouse accessible to the public containing information from Reasonably Achievable Control Technology (RACT), BACT, and LAER determinations made by pollution control agencies within the United States. The clearinghouse function is to provide state and local agencies with current control technology determinations, to summarize recent determinations for sources of similar size and nature, to provide data on specific emission limits imposed on existing, new, or modified sources across the United States, and to allow posting of permit information by state authorities. Update of information in the BACT/LAER system is the responsibility of designated users at each pollution control agency; therefore, the completeness and accuracy of the data will depend on the priority and resources allocated by each of the contributing agencies.

BLIS contains information of specific facilities including whether the facility is new or modified, process types, the basis for the limit (RACT, BACT, LAER, NSPS), operating parameters such as capacity, pollutant emission limits, and control technology, permit dates, and agency contacts. Data are organized so that each facility has at least one process emission source and one pollutant, although generally, facility determinations detail multiple sources and pollutants. The permanent BLIS database contains determinations for the past five years; however, two additional databases are accessible: a historical database which contains determinations more

[48] http://www.epa.gov/ttn/nsr/

than five years old and a transient database which includes determinations for permits not yet issued, or where information is missing or unverified.

Actual emission data, manufacturer's guarantees, and test data are not available from the permits; this type of information is generally submitted as part of the permit application or compliance demonstration process and is not easily accessible. It is important to recognize there are limitations of the information obtained from the BLIS database: the search cannot be considered an exhaustive one and negotiation and issuance of permits is an on-going and evolving process such that the trend toward more stringent limits will continue.

A - 3.3 New Source Performance Standards (NSPS)

A - 3.3.1 Kraft pulp mills

The New Source Performance Standards (NSPS) for kraft pulp mills promulgated in 1978 established emission limits for PM and TRS compounds from various kraft pulping process units such as digester systems, multiple-effect evaporator systems, brownstock washers, and condensate strippers. All kraft pulp mills constructed or modified after September 24, 1976 are subject to these NSPS requirements. Emissions of SO_2 and NO_x were not to be regulated under the NSPS for kraft pulp mills and this continues to be the case. However, NO_x, PM, and SO_2 are regulated under NSPS for wood, oil and natural gas fired industrial boilers, but excludes kraft recovery boilers. NSPS for these power boilers are discussed in the next subsection. Most states have regulations for existing operations and use the federal NSPS for new operations in conjunction with a BACT review at the time of the permit application. The federal NSPS, which applies only to new and modified sources, is generally adopted by reference and administered by each state pollution control regulatory authority.

PM emissions from the five principal kraft pulp mill emission sources (e.g., recovery furnace, smelt dissolver, lime kiln/calciner, wood-fired power boiler, and oil-fired power boiler) are regulated by the federal NSPS. PM emissions from recovery furnace, smelt dissolver, lime kiln/calciner, and NCG system are regulated by several states as are the PM emissions from the paper/pulp machine and power boilers. The recently promulgated MACT II standards described in more detail further on has upgraded the PM standards of existing sources to the NSPS limits for new sources and also changed the PM standards of new sources to more stringent limits. Details of the PM standards are provided in the MACT II description, Section A - 3.4.2.

Almost all US jurisdictions regulate opacity and require continuous emission monitoring. Although only opacity from the recovery furnace and power boilers is regulated by the federal NSPS, all of the selected states regulate opacity for each emission source. The federal NSPS and the state of Oregon require continuous emission monitoring for opacity from recovery furnaces; federal NSPS and several of the selected states also require continuous emission monitoring for industrial boilers.

The NSPS vent stack opacity limits are:

- Kraft recovery furnace opacity limit of 35%;
- Wood, oil, or gas fired auxiliary power boilers opacity limit of 20%.

Total reduced sulphur (TRS) emissions from eight kraft pulp mill emission sources are regulated by the federal NSPS. The number of states regulating TRS emissions from kraft pulp mills varies depending on the type of emission sources, with some emission sources being regulated by only one state (e.g., tall oil plant) while others are regulated by most states (e.g. recovery furnace). NSPS require continuous emission monitoring for TRS and oxygen content from most of these sources. NSPS has a provision of exemption for brownstock washer systems if demonstrated that control of TRS is technologically or economically unfeasible. Under this provision, few washer systems have TRS limits and controls specified in the permit. However, the MACT I standards for HAPS does include limits and controls for washer system vents that will require most systems to collect and incinerate the vapours for HAPS reduction, with the indirect benefit of TRS emission reduction.

The NSPS vent stack TRS limits are:

- Digester, brownstock washer, evaporator, or condensate stripper systems TRS limit of 5 ppm_{DV} at 10% oxygen or:
  - Gases are combusted in lime kiln, recovery furnace, or incinerator having a minimum of 1200°F temperature for at least 0.5 seconds;
  - Demonstrate to EPA's satisfaction that incineration of brownstock washer system vents is technologically or economically unfeasible;
  - Gases from digester, brownstock washer or condensate stripper systems are controlled by a means other than combustion to a TRS limit of 5 p ppm_{DV}; and
  - Uncontrolled exhaust gases from digester system are less than 0.005 g/kgAD Pulp.
- Kraft recovery furnace TRS limit of 5 ppm_{DV} at 8% oxygen.
- Kraft/sulphite cross recovery furnace TRS limit of 25 ppm_{DV} at 8% oxygen.
- Smelt dissolving tank TRS limit of 0.016 g/kg of black liquor solids as H_2S.
- Lime kiln TRS limit of 8 ppm_{DV} at 10% oxygen.

NSPS regulate SO_2 emissions from only one source, oil fired power boilers. The number of states regulating SO_2 emissions from each potential source varies. Neither federal nor state regulations have specific continuous emission monitoring requirements for SO_2, although individual permit conditions may require monitoring for this pollutant. NO_x emissions from kraft pulp mills are not regulated by state or federal emission standards. However, NO_x emissions from industrial boilers including combination wood and fossil fuel (oil, gas) boilers are regulated by federal NSPS and include continuous emission monitoring requirements.

A - 3.3.2 Power boilers

The New Source Performance Standards (NSPS) applicable to industrial boilers were introduced first in 1971 to control emissions from new sources and older sources that undergo major modification. NO_x, PM, and SO_2 are regulated under NSPS for wood, oil, natural gas and coal fired industrial boilers. There have been numerous extensions of applicability to combination wood and fossil fired units and to smaller units over the years limiting end-of-stack emissions, defining monitoring requirements and sampling measurement methods. The regulations are complex and depend on magnitude of fuel heat input, date of modification, fuel types, % of fuels in co-firing situations among other factors.

A new Rule (regulation) was introduced 13 June 2007 for boilers constructed, or modified with a performance test date after 28 Feb 2005 that are more restrictive than previous. These changes are found in the Federal Register 40 CFR Part 60 Subpart Db[49].

Table A - 17: NSPS Limits for Industrial Boilers – Subpart Db

Fuels or combinations of fuels	Emission Limits in g/GJ		
	NOx	PM	SO_2
Coal	210-260g/GJ (a)	13g/GJ or 99.8% red. (e)	87g/GJ or 92% red. (b)
Gas	43--86g/GJ (c)	-	-
Oil, distillate (#2) residual (#6)	43-86g/GJ (c) 130-170g/GJ (c)	13g/GJ or 99.8% red. (a)	87g/GJ or 92% red. (b)
Wood if wood is <30% heat input	130g/GJ (d)	13g/GJ or 99.8% red. (a)	87g/GJ or 92% red. (b)
Wood if wood is >30% heat input			
<264GJ/h heat input	130g/GJ (d)	43g/GJ	87g/GJ or 92% red. (b)
>264GJ/h heat input	130g/GJ (d)	37g/GJ	87g/GJ or 92% red. (b)

Notes: a – NOx: Varies according to the furnace type and for some coal types. The contraction 'red.' is used for 'reduction'.

b – SO_2: 87g/GJ limit or 92% reduction of potential SO_2 emission at an uncontrolled emission rate specified at 520g/GJ.

c – NOx: Higher number applies to units with a heat release rate > than 70 000Btu/h/ft^3, e.g., typically package boilers.

d – NOx: For units with an annual capacity (utilization) factor for gas > than 10%.

e - PM: Only if a modification, 99.8% reduction of the combustion PM emission concentrations and, as well, meet 22g/GJ.

[49] http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=59da36c1ba5cc91111a68e57ecb8fdd0&rgn=div8&view=text&node=40:6.0.1.1.1.11.121.4&idno=40

A - 3.4 National Emission Standards for HAPs and MACT Limits

US EPA has developed hazardous air pollutant (HAP) emission standards for the pulp and paper industry through which they enforce nationally uniform standards to control particular hazardous air pollutants. National Emission Standards for Hazardous Air Pollutants (NESHAP)[50] is a list of 189 HAPs and 174 categories of sources. The controlling regulations are based on Maximum Achievable Control Technology (MACT).

MACT is an emission standard or emission rate based upon best demonstrated control technology and practices. MACT limits must be as stringent as the average emission limit achieved by the 12% best performing mills. Existing sources must meet MACT emission requirements and new sources must match or improve upon these requirements. The MACT I standard for kraft, sulphite, semi-chemical, and soda pulp mills was included with effluent guidelines published in the Federal Register in December 1993 and is titled "the Cluster Rule" because it is a regulatory approach that integrates both the air and the effluent rulemaking into a consolidated process.

In general, MACT standards for the pulp and paper industry do not require specific process technologies. However, a combination of process changes and add-on controls will be required in order to control HAP emissions and comply with either a specific percent reduction or mass of pollutant emitted per ton of product requirements.

For the pulp and paper industry, the Phase I of the Cluster Rule regulation covering MACT I and MACT III was published in the Federal Register on April 15, 1998[51], and the final rule for MACT II was published on January 12, 2001.[52] The MACT for industrial boilers was published in the Federal Register on 13 September 2004[53]. The MACT parts that relate to pulp and paper industry sources are organized as follows:

- MACT I – covers process sources in pulping, bleaching, and wastewater areas for chemical pulp mills, including kraft, stand-alone semi-chemical, and sulphite pulping;
- MACT II – covers combustion sources at kraft, soda, semi-chemical, and sulphite mills, including recovery units, smelt-dissolving tanks, and lime kilns;
- MACT III – covers air emissions from paper machine, mechanical pulping, and pulping of secondary fiber and non-wood fiber; and
- The MACT - industrial boilers and heaters cover power boilers and heaters fired with gas, oil, coal, and other solid fuels such as wood, bark, and sludge.

[50] http://www.epa.gov/ttn/uatw/pulp/pulppg.html
[51] 63 FR 18504, http://www.epa.gov/ttn/atw/pulp/pulppg.html
[52] 66 FR 3180, http://www.epa.gov/ttn/atw/pulp/pulppg.html
[53] http://www.epa.gov/ttn/atw/boiler/boilerpg.html

A - 3.4.1 MACT I

Pulping system standards for kraft, semi-chemical, and soda mills require collection and treatment of a specified list of concentrated non condensable gas (CNCG) vent sources. Applicable sources include digester, turpentine, evaporator, and steam stripper systems. New and modified sources must be in compliance upon start-up while existing sources have three years after the Cluster Rule date of publication, but perhaps subject to negotiation and permit renewal date.

Dilute non condensable gas (DNCG) vent sources from new and existing kraft pulping systems also have a list of streams for collection and treatment. Applicable sources include knotting (if greater than 0.1 lb HAP per OD ton pulp) and screening (if greater than 0.1 lb HAP per OD ton pulp), pulp washing, deckers (if not using fresh water, paper machine white water, or process water having less than 400 ppm wet basis HAP), and oxygen delignification systems. However, a notable exception is that several existing DNCG sources (brown stock washers and oxygen delignification systems) have an optional compliance schedule of eight years. Only new DNCG sources at semi-chemical and soda pulping systems require collection and treatment. A special provision called the Clean Condensate Alternative (CCA) allows for avoidance of collection of select DNCG sources provided that HAP controls, other than those already required, are implemented with a net overall mill site reduction of HAPs release that is equal or greater than the emission reduction by collection of the DNCGs.

For all pulping vent sources, methanol can be used as a surrogate for total hazardous air pollutants (HAPs). Control options include:

- Achieving a 98% HAPs reduction;
- Thermal oxidation in a dedicated incinerator; and
- Thermal oxidation in a boiler or lime kiln.

Sulphite pulping systems also have a specified list of NCGs for existing and for new sources for collection and treatment. Emission limits from the control device differ between calcium/sodium based and ammonium/magnesium based pulping system.

Bleaching systems at all chemical pulp mills have standards specific to chloroform and chlorine emissions. Chloroform control is achieved by not allowing use of chlorine or hypochlorite in any bleaching stage. Bleaching stages that use a chlorinated compound such as chlorine dioxide must collect the system vents and treatment of the gas to one of three alternates of chlorine emission limits:

- Treatment of vent stream to 99% HAP (Cl_2) removal;
- Treatment of vent stream to outlet HAP (Cl_2) concentration of 10 ppm_{DV} or less; and
- Treatment of vent stream to HAP (Cl_2) emissions equal to or less than 0.0002 lb per OD ton pulp.

Additionally, HAPs potentially released from process condensates have emission standards. Foul condensates from a specified list of new and existing chemical pulping systems must be collected and treated. Applicable condensate sources include digester, turpentine, evaporator weak liquor feed stage vapour, and CNCG and DNCG condensate systems. Volume reduction options such as condensate segregation are specified and methanol can be used as a surrogate for total HAPs. Control device options include recycle of condensates to vent controlled equipment, biotreatment, or steam stripping.

A - 3.4.2 MACT II

At all chemical pulp mills, MACT II standards are applicable to emissions from chemical recovery units (kraft and soda recovery boilers, sulphite recovery furnaces, and semi-chemical combustion units) smelt dissolving tanks, and lime kilns. Regulated emissions include particulate matter (PM), particulate hazardous air pollutants (PMHAP), and total gaseous organic HAP. New and modified sources must be in compliance upon start-up while existing sources have three years after the Cluster Rule publish date of January 12, 2001, but perhaps subject to negotiation.

The MACT II standards have essentially replaced the NSPS limits for kraft pulp mills and also added PM limits for sulphite recovery units. Under MACT II, existing recovery boilers and furnaces, and smelt dissolving tank vents are required to meet the previous NSPS PM levels. New source standards for recovery boilers and smelt dissolving tanks in MACT II are based upon emissions from modern, efficient electrostatic precipitators and wet scrubbers, respectively.

All existing lime kilns must meet the current NSPS PM limits for gas-fired kilns. New source standards are based upon emissions from modern, efficient electrostatic precipitators.

Kraft and soda mills can choose to comply with MACT II standards by each source independently, or as a site "bubble" limit. The site bubble excludes the effluent treatment plant.

The following Table A - 18, Summary of Promulgated Standards, provides the specific limits for MACT II, and is a copy from the final MACT II rule 40 CFR 63 published January 12, 2001 FR Vol 66, No. 9, page 3183.

Table A - 18: Summary of Promulgated MACT II Standards for combustion sources

TABLE 1. SUMMARY OF PROMULGATED STANDARDS[a]

Subcategory	Emission point	HAP metals standard		Alternate HAP metals standard ("bubble")[a]		Gaseous organic HAP standard	
		Existing	New	Existing	New	Existing	New
Kraft and soda	Recovery furnaces (NDCE and DCE)	PM ≤ 0.10 gr/dscm (0.044 gr/dscf) at 8% oxygen	PM ≤0.034 g/dscm (0.015 gr/dscf) at 8% oxygen	Mill-specific PM emission limit (kg/Mg (lb/ton) BLS) based on calculated value of the sum of the individual emissions limits for recovery furnaces, SDT, and lime kilns. See equation 1 in §63.865(a)(1) of the final rule.	No "bubble" alternate standard for new sources	No standard	Gaseous organic HAP ≤ 0.012 kg/Mg (0.025 lb/ton) BLS (as measured by methanol)
	SDT	PM ≤ 0.10 kg/Mg (0.20 lb/ton) BLS	PM ≤ 0.06 kg/Mg (0.12 lb/ton) BLS			No standard[b]	No standard[b]
	Lime kilns	PM ≤ 0.15 g/dscm (0.064 gr/dscf) at 10% oxygen	PM ≤ 0.023 g/dscm (0.01 gr/dscf) at 10% oxygen			No standard[b]	No standard[b]
Sulfite	Sulfite combustion units	PM ≤ 0.092 g/dscm (0.040 gr/dscf) at 8% oxygen	PM ≤ 0.046 g/dscm (0.020 gr/dscf) at 8% oxygen	Not applicable	Not applicable	No standard[b]	No standard[b]
Stand-alone semi-chemical	Semichemical combustion units	No standard	No standard	Not applicable	Not applicable	Gaseous organic HAP ≤ 1.49 kg/Mg (2.97 lb/ton) BLS (as measured by THC) OR 90% reduction	Gaseous organic HAP ≤ 1.49 kg/Mg (2.97 lb/ton) BLS (as measured by THC) OR 90% reduction

[a] g/dscm = grams per dry standard cubic meter, gr/dscf = grains per dry standard cubic foot, kg/Mg = kilograms per megagram, lb/ton = pounds per ton, BLS = black liquor solids, and THC = total hydrocarbons.

[b] Emissions of gaseous organic HAP from these sources are regulated as part of the NESHAP for noncombustion sources at pulp and paper mills.

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A - 3.4.3 MACT III

MACT III is the HAP air standard for paper machines, mechanical pulping and secondary fibre and nonwood pulping mills. New limits are established for bleaching systems that use chlorine

or chlorine dioxide. Vents streams must be collected and treated to the emissions limits of chlorine. Compliance options are the same as for chemical pulp bleaching: treatment of vent stream to either 99% HAP removal, outlet HAP concentration of $10ppm_{DV}$ or less, or HAP emissions equal to or less than 0.0002 lb/OD ton pulp. The surrogate HAP is chlorine. New and modified sources must be in compliance upon start-up while existing sources have three years after the Cluster Rule publish date. Although the paper machine MACT III rule is final, a separate NESHAP rule was proposed by EPA in September 2000 that covers emission limits and controls for organic HAPS from paper web coating operations. The final rule would include major source paper mills that have applicable organic HAPS in their coatings and operate on-machine or off-machine paper coating systems.

A - 3.4.4 MACT for industrial boilers and heaters

MACT for industrial boilers was published in the Federal Register on 13 September 2004[54]. They were to come into effect on 13 September 2007. However, on July 2007 this regulation met a legal challenge and has been withdrawn[55] by the US EPA. The challenge revolves around the definition of what is waste fuel as there is potential overlap with the rule that applies to solid waste incinerators. The US EPA will be appealing the verdict and is in the process of renegotiating with the plaintiffs, and will reapply. The process will be time consuming and will probably involve determining what is in solid waste as found in an industry like pulp and paper and what is in commercial and domestic solid waste, i.e., garbage. The reapplication could take about 2 years[56].

Limits are imposed for HCl, total metals or particulate matter as a surrogate for total metals, and mercury emissions from boilers burning solid fuels in existence or under construction as of January 2003. The limits apply to units with heat input capacities exceeding 10MBtu/hr, but do not apply to fire-tube type boilers. Existing boilers must be in compliance with the applicable limits no later than September 2007. The emission limits for existing and new boilers are shown in Table A - 19 and A - 20.

[54] http://www.epa.gov/ttn/atw/boiler/boilerpg.html
[55] http://www.michaelbest.com/resources/publications/1954.pdf
[56] This clarification on the rule from a phone conversation with Jim Eddinger, USEPA 12 Oct 2007 (919) 541-5426.

Table A - 19: Proposed MACT for Solid Fuel Boilers and Process Heaters

	Units	Existing Units (c)	New or reconditioned Units
Particulate Matter	lb/MBtu / g/GJ	0.07 / 30 (a)	0.025 / 10.8
Total selected Metals	lbx10^{-3} /MBtu / g/GJ	1.0 / 0.43 (a)	0.3 / 0.13
HCl	lb/MBtu / g/GJ	0.09 / 39	0.02 / 8.6
Mercury (Hg)	lbx10^{-6}/ MBtu / µg/GJ	9 / 3.9	3 / 1.3
CO at 7% O_2 by volume, dry	ppm	No limit	400 (b)

Notes: a - For limited use units (<10% of the time), PM limit is 0.21 lb/MBtu, or total selected metals limit is 0.004 lb/MBtu.

b - No CO limit for small units under 10MBtu/h heat input.

c - No limits for small units under 10MBtu/h heat input

Table A - 20: Proposed MACT for Liquid Fuel Boilers and Process Heaters

	Units	Existing Units	New or reconditioned Units
Particulate Matter	lb/MBtu / g/GJ	0.07 / 30	0.03 / 13
Total selected Metals	lbx10^{-3} /MBtu / g/GJ	1.0 / 0.43	-
HCl	lb/MBtu / g/GJ	0.09 / 39	0.0005 / 0.21 (b)
Mercury (Hg)	lbx10^{-6} / MBtu / µg/GJ	9 / 3.9	-
CO at 7% O_2 by volume, dry	ppm	No limit	400 (a)

Notes: a - No CO limit for small units under 10MBtu/h heat input.

b - HCL limit of 0.0009 for small units under 10MBtu/h heat input and limited use units (<10% of the time).

Limited use units are defined as having an annual fuel heat input of less than 10% of the maximum possible annual fuel heat input. The solid fuel limits apply to boilers co-firing solid fuels with liquid and/or gaseous fuels. There are no emission limits for existing boilers that fire only liquid or gaseous fuels.

Compliance can be demonstrated with the HCl, mercury, or total selected metals emission limit for a solid fuel boiler through fuel analyses alone. Each type of fuel that can be burned in the boiler must be analyzed for heat content, moisture content, and the relevant pollutant (mercury, chlorine, or the 8 selected metals) so that a potential emission rate in lb/106 Btu can be calculated for mercury, HCl, or total selected metals. When stack testing is used to demonstrate compliance, concurrent analyses of the fuel must also be conducted.

As an alternative to complying with the HCl limit, the MACT rule allows facilities with solid fuel boilers to demonstrate that their boiler HCl emissions do not pose a significant health risk. This health-based compliance alternative involves making emission measurements of HCl and chlorine, and estimating, through dispersion modeling, ambient concentrations at the property fenceline. A similar health based option is available for metals, where manganese emissions are considered separately from the other seven metals.

New boilers or process heaters, i.e., those on which construction started after January 2003, are subject to a carbon monoxide limit as a surrogate for products of incomplete combustion from the burning gaseous, liquid, or solid fuels. Solid fuel new units have more stringent limits than those for existing units.

As mentioned earlier these MACT rules for industrial boilers have met a legal challenge and have been withdrawn by the US EPA.

A - 3.4.5 MACT standards for monitoring and reporting

The MACT standards include many new requirements for system monitoring, record keeping, and reporting. In instances when continuous emission monitoring is not specifically required by regulation, the permitting authority may impose this requirement or a source test requirement on the source in the permit.

Monitoring, testing, and reporting requirements have become more uniform with the implementation of Title V of the 1990 Clean Air Act Amendments and the Cluster Rule MACT standards. Title V requires all states to implement an operating permit program for major sources, e.g., sources emitting 100 short tons per year of any criteria pollutant (lower thresholds for hazardous air pollutants are also defined). One of the major impacts of the operating permit program will be the compliance demonstration documentation requirement, including continuous emission monitoring for many types of sources.

Maine is a state that has more stringent mass emission limits of chlorine and chlorine dioxide from bleach plants and chemical preparation plants (chlorine dioxide generator) at kraft pulp mills.

A - 4 Regulations in the EU

The European Union (EU) has a set of common rules on permitting for industrial installations called the Integrated Pollution Prevention and Control (IPPC) Directive which were introduced in 1996. The IPPC Directive is aimed towards minimizing point source pollution throughout the EU and incorporates integrated permitting that "...must take into account the whole environmental performance, i.e. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, preventions of accidents, risk management, etc.". It imposed on new and existing listed industries undergoing substantial change permit obligations covering air, water, soil, energy use and chemical use since 30 October 1999. Other existing installations must be brought into compliance by 30 October 2007.

The IPPC Directive is based on four principles[57]:

- ***An integrated approach*** The integrated approach means that the permits must take into account the whole environmental performance of the plant, covering e.g. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure. The purpose of the Directive is to ensure a high level of protection of the environment taken as a whole.
- ***Best Available Techniques*** The permit conditions including emission limit values must be based on Best Available Techniques (IPPC-BAT), as defined in the IPPC Directive. To assist the licensing authorities and companies to determine BAT, the Commission organises an exchange of information between experts from the EU Member States, industry and environmental organisations. This work is co-ordinated by the European IPPC Bureau of the Institute for Prospective Technology Studies at EU Joint Research Centre in Seville, Spain. This results in the adoption and publication by the Commission of the BAT Reference Documents (the so-called BREFs.
- ***Flexibility*** The IPPC Directive contains elements of flexibility by allowing the licensing authorities to determine permit conditions to take into account:
  (a) the technical characteristics of the installation;
  (b) its geographical location; and
  (c) the local environmental conditions.
- ***Public Participation*** The Directive ensures that the public has a right to participate in the decision making process and to be informed of its consequences by having access to:
  (a) permit applications in order to give opinions;
  (b) permits;
  (c) results of the monitoring of releases; and
  (d) the European Pollutant Release and Transfer Register, where emission data reported by Member States are made accessible in a public register, which is intended to provide environmental information on major industrial activities.

Each EU member country must issue its own operating permits to existing and new pulp and paper facilities. Implementation of the permit and compliance monitoring remains within the authority of each Member State, but specific limits must be as stringent as the IPPC Directive conditions. Member States can decide to implement permitting in a phased approach to avoid any economic disadvantages to older facilities that may require radical environmental improvements to achieve IPPC-BAT.

For the pulp and paper industry, the first BREF report[58] was published by the European Commission in December, 2001. The BREF contains chapters describing the industry, economic situation, environmental issues, types of mills and processes used, and associated emission levels, techniques to consider in determination of IPPC-BAT, emerging technologies and operating techniques and IPPC-BAT range of achievable emission levels.

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[57] http://ec.europa.eu/environment/ippc/index.htm
[58] http://eippcb.jrc.es/pages/FActivities.htm

In anticipation of future revision, some clarification and needed emphasis of presentation in the BREF for pulp and paper is suggested in a recent document[59]. An important aspect of BREF is that the emission standards are not to be interpreted as suitable limit values for permits. The emission value or a range of emission values are representative of what the IPPC-BAT is reasonably capable of and are

> *"…thus to provide general indications regarding the emission …… levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values."*

The document goes on to state the specific reasons why it is wrong for IPPC-BAT emission limit values to be used as permit limit values which are:

- BAT levels are based on annual averages, which are insufficient for permits;
- Permit limits are based on National Legislation;
- The Local environmental and socioeconomic conditions need to be taken into account in permit limits. The local conditions can either tighten or loosen the permit limits;
- Site-specific factors, for example technical characteristics of a mill and its product portfolio, must be considered in the permitting process and for the permit limits; and
- The BAT values presented in BREF are not generated in a systematic way as they are taken from heterogeneous data sources.

In September 2006, an EU Technical Working Group for the Review of BAT for the Pulp and Paper Industry met to discuss developments in best available techniques in the pulp and paper industry that have occurred since the first BREF report of 2001. The Group concluded that the BREF document and possibly IPPC-BAT emission levels needed updating and review. Mindful of the 4 years (1997 – 2001) needed to issue the first BREF report for pulp and paper, work started in 2006.

The European Commission[60] on 21 December 2007 adopted new legislation on industrial emissions to strengthen the provisions already in force and reduce industrial emissions throughout the European Union. The proposal will bring significant health and environmental benefits and will create a better level playing field across the EU, reducing competition distortions between companies. The motivation is that industrial emissions in the EU remain too high and are having detrimental effects on human health and the environment. Clearer and stricter rules are needed to ensure that industrial installations comply with the necessary high environmental standards across the EU. The EU must ensure that companies meet their obligations and use the best available techniques. The aim of the new directive is to tackle the shortcomings of current legislation on industrial emissions. The main thrust of the directive is to increase the use of IPPC-BAT, an obligation to ensure that industrial operators use the most cost-effective techniques to achieve a high level of environmental protection.

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[59] http://www.ymparisto.fi/download.asp?contentid=65130&lan=EN

[60] http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1985&format=HTML&aged=0&language=EN&guiLanguage=en

Due to the weakness of existing legislation, there has not been the level of application of BATs required by the IPPC Directive across the EU. Compliance with and enforcement of current legislation in the different Member States is also inconsistent and the complex legal framework carries unnecessary costs for industry. These issues need to be addressed in order to maintain a level playing field for industry while offering higher levels of protection for the environment and human health.

The most recent figures on the issuing of permits under the directive suggest that by mid-2006 only about 50% of the 52,000 installations concerned had received a permit. This regrettable situation shows Member States have not made sufficient efforts to comply with the directive's deadline of 30 October 2007.

The range of IPPC-BAT limit values are presented in Table A – 24 of Section A – 8 of this Appendix.

A - 5 Regulations in Sweden

Sweden is divided into 24 counties called Län and 270 local authority areas called Kommun. There are no national or county guidelines for air emissions from kraft pulp mills in Sweden.

The administration of environmental matters is handled by:

- the Swedish Environmental Protection Agency (SEPA);
- the National Licensing Board for Environmental Protection ("Franchise");
- the Län Administration license; and
- local environmental and health protection boards.

Sweden, like other EU countries, is subject to policies approved by the European Commission. Several important legislative and policy initiatives have occurred since Sweden's integration in1994 which have impacted the pulp and paper sector. A key policy initiative affecting the European pulp and paper sector is the 1996 European Union Council Directive (IPPC Directive) concerning integrated pollution prevention and control and the requirement to use Best Available Techniques (IPPC-BAT) discussed in a preceding section.

This EU directive caused Sweden to implement the Swedish Environmental Code in 1999 which amalgamated and updated 15 existing environmental laws. The Swedish Environmental Code requires the use of Best Available Techniques (IPPC-BAT) for all activities that have the potential to cause pollution.

Limits are set by the Environmental Court (Miljödomstolen) on an individual basis for each mill. Concentration limits for specified emission points are only given for particulate matter (PM). There are, however, H_2S concentration limits for the recovery boiler and the lime kiln that must not be exceeded for a given percentage of the operating time. Millwide limits for sulfur and NOx

emissions are given in kilograms per air dry metric tonne (kg/ADt). A typical permit for modern mills can be as shown in Table A - 21[61].

Table A - 21: Preliminary air emission permit in a Swedish BKP mill

	Units	Permit Limits
Millwide Sulphur	kg S/ADt (annual average)	0.4-0.6
Millwide NOx	kg NO_2/ADt (annual average)	1.2-1.5
PM Recovery Boiler	mg/NDm3 at actual O_2 (monthly average)	60-100
H_2S Recovery Boiler	mg/NDm3 at actual O_2 (monthly average)	10 for more than 95-99% of the time
PM Lime Kiln	mg/NDm3 at actual O_2 (monthly average)	60-250
H_2S Lime Kiln	mg/NDm3 at actual O_2 (monthly average)	50 for more than 90% of the time
PM Power Boiler(bark)	mg/NDm3 at 10% O_2 (monthly average)	60-250
PM Power Boiler(oil)	g/kg oil	1.5

Notes
a - There is no specified % O_2 reference level in the limits (with the exception of CO_2 for the power boiler). The reference level for normal operation is about 2.3% O_2.

b - The limits show the lowest and highest figures from some recent permits. The ranges depend on the age and condition of the equipment in the mill, i.e. the lowest figures for the recovery boiler refer to a mill with a new boiler.

The administrative advantage for the Environmental Court with the use of the mill wide emission intensity approach is that all emission points in a mill are covered, including lower-strength point sources. There are advantages also for the mill, as there is the possibility for optimizing the emission control expenditures among the sources where the best cost-benefit is lowest. This gives the required results for the minimum cost.

A - 6 Regulations in Finland

Finland is subject to policies approved by the European Commission, including integrated pollution prevention and control and the adoption of IPPC-BAT. This directive caused Finland to enact the Finnish Environmental Protection Act in 2001. The Act replaced two previous pieces of legislation that provided the authority to permit emissions and wastewater discharges from pulp and paper mills. As a result of the Act, all pulp and paper mills were required to apply for new integrated permits by December 31, 2004. For each mill, the new permit replaced a multiplicity of permits that existed before which depended on the various separate laws, acts and ordinances.

The 2001 Finnish *Environmental Protection Decree* specifies what must be considered by industry and regulators when assessing IPPC-BAT. This document requires a holistic approach considering pollution prevention, energy efficiency, accident prevention, environmental impact and other factors in addition to a requirement to consider

[61] This table is taken from the *Study Report For Independent Advice On The Development Of New Environmental Emission Limit Guidelines For Any New Bleached Eucalypt Kraft Pulp Mill in Tasmania*, Resource Planning and Development Commission, Tasmania, Aug 2004
http://www.rpdc.tas.gov.au/bekm/final_report
http://www.rpdc.tas.gov.au/bekm

IPPC-BAT information published by the European Commission.

Limits are set by the Agency for Environmental Permits (Miljötillståndsverket) on an individual basis for each mill. There are no national or county (called Län) guidelines for air emissions from kraft pulp mills in Finland. Permits are awarded by environmental boards, regional environmental offices or Län administration depending on the size of the project.

As a result of this recent re-permitting process, the mills have been brought into line with Best Available Techniques as defined by the IPPC process.

The compliance agency remains the responsibility of the county (Län) administration and local boards as they were before Finland joined the EU. Upsets and malfunctions that generate emissions exceeding permit limit values must be reported without delay to the inspection authority and local boards.

The limits presented in Table A - 22 are from a recent preliminary permit to a Finnish pulp and paper mill[62]. The limits would not be applicable during start-ups and shut-downs, nor during process upsets. Separate regulations would be given for these events.

Table A - 22: Preliminary air emission permit in a Finnish BKP mill

	Units	Permit Limits
Millwide Sulphur	kg S/ADt (annual average)	0.40
Millwide NOx	kg NO_2/ADt (annual average)	1.5
PM from Recovery Boiler	mg/NDm3 at 6% O2 (daily average)	50
TRS from Recovery Boiler	mg S/NDm3 at 6% O2	10 for more than 98% of the time
NOX from Recovery Boiler	mg NO_2/NDm3 at 6% O2 (monthly average)	200
SO_2 from Recovery Boiler	mg SO_2/NDm3 at 6% O2 (monthly average)	100
PM from Lime Kiln	mg/NDm3 at 6% O2 (daily average)	60
TRS from Lime Kiln	mg S/NDm3 at 6% O2	20 for more than 98% of the time
NOX from Lime Kiln	mg NO_2/NDm3 at 6% O2 (monthly average)	500
SO_2 from Lime Kiln	mg SO_2/NDm3 at 6% O2 (monthly average)	200

It is noteworthy that the permit includes both millwide limits and concentration-based limits for NOx and sulfur. This is unusual since, as in Sweden, air emission permits for kraft mills in Finland normally include only millwide limits for NOx and sulfur.

[62] Resource Planning and Development Commission: *Study Report For Independent Advice On The Development Of New Environmental Emission Limit Guidelines For Any New Bleached Eucalypt Kraft Pulp Mill in Tasmania*, Aug 2004
http://www.rpdc.tas.gov.au/bekm/final_report
http://www.rpdc.tas.gov.au/bekm

A - 7 Regulations of the World Bank

Pulp and paper industry projects that solicit and use financing from the World Bank Group (WBG) must comply with their policies and guidelines which emphasize pollution prevention, including the use of cleaner production technologies.

One of several members of the Group is the International Finance Corporation (IFC), which is often involved with new pulp and paper mills in the developing world. IFC mandate is the promotion of economic development through partnership with the private sector. Working with business partners, it invests in sustainable private enterprises in developing countries that have limited access to capital. It provides finance in markets deemed too risky by commercial investors in the absence of IFC participation and adds value to the projects it finances through its corporate governance, environmental, and social expertise.

Environmental, Health, and Safety (EHS) Guidelines are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them. The EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The EHS Guidelines replace those documents previously published in Part III of the Pollution Prevention and Abatement Handbook.

In the case of pulp and paper industry, the EHS consist of two parts:

- The General EHS Guidelines[63] which are technical reference documents for industry in general covering environmental, occupational and community health and safety, construction and decommissioning; and
- The EHS Guidelines for Pulp and Paper Mills[64].

The EHS Guidelines include describe pollution prevention measures, identify environmentally cleaner production technologies and tabulate emission performance guidelines reflective of what the WBG call Good International Industry Practice, GIIP. GIIP is defined as:

> *..... the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.*

The General EHS Guidelines were introduced in April 2007, the pulp and paper industry in December 2007. These supercede the WBG's Pollution Prevention and Abatement Handbook.

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[63] http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_GeneralEHS/$FILE/Final+-+General+EHS+Guidelines.pdf

[64] http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_PulpandPaper/$FILE/Final+-+Pulp+and+Paper+Mills.pdf

An initial environmental assessment is performed on the basis of the host country's legislation and the general and industry-specific EHS Guidelines. As regards air emissions, there are thresholds established (PM10>50t/a, NOx and SOx each > than 500t/a) the project is deemed capable of significant impacts and should miminimze those impacts to ensure that ambient air quality guidelines whether national or those of the World Health Organization are met. The contribution of the project should not exceed 25% of the ambient air quality guidelines, based on local air quality assessments and dispersion modeling using internationally recognized software and procedures. Special requirements would be sought in the case of degraded air sheds that do not meet ambient air quality guidelines. The guidelines set source emission concentration limits for small combustion facilities firing gas, oil or solid fuel (wood, coal) of between 3 and $50MW_{thermal}$ heat input basis. For larger combustion facilities, the WBG Thermal Power Guidelines are to be followed (new guidelines are currently in progress but not available[65]). The guidelines limit values for small combustion facilities are presented in Table A – 24 of Section A – 8 at the end of this Appendix.
The guidelines also include requirements covering fugitive and greenhouse gas emissions and energy conservation.

The EHS guidelines for pulp and paper mills recommends modern technology and systems design for CNCG collection and incineration with backup (standby) incineration to minimize venting to atmosphere. For DNCG systems the recovery boiler is the preferred point of incineration, a backup incineration point should be installed in cases where the mill is in proximity to residential areas. Point of discharge of vented NCG should be from the recovery or power boiler stack.

The pulp and paper guidelines go on to recommend firing black liquor at 75% solids or higher, controlling the recovery boiler combustion process to reduce sulphur and nitrogen oxide emissions, and other measures to control lime kiln emissions. Annexes to these guidelines describe modern pulp and paper process technologies in use today, and give guideline values for emissions, electrical and heat energy use rates and water consumption on a per tonne basis. Table A - 23 presents the Pulp and Paper Guideline values for kraft pulping.

[65] The existing Guidelines date from 1998. See http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

Table A - 23 World Bank Air Emission And Energy Guidelines for Kraft Pulp Mills

	Units	Permit limits
AIR EMISSIONS		
NOx as NO_2, Softwood	kg NO_2/ADt (annual average)	2.0
Hardwood	kg NO_2/ADt (annual average)	1.5
PM	kg /ADt (annual average)	0.5
SO_2	kg S/ADt (annual average)	0.4
TRS	kg /ADt (annual average)	0.2
ENERGY CONSUMPTION		
Heat	GJ/ADt	10 - 14
Power	kWh/ADt	600 - 1200

A - 8 Emission Limit Comparison for Selected Jurisdictions

Table A-24 overleaf is a repeat of Table 2 - 4 of Section 2 and presents a comparison of the best current requirements for the many of the jurisdictions described in the foregoing section, all at the standard conditions of 25°C, 101.325kPa and the reference oxygen contents consistent with Alberta Environment.

Table A - 24: Emission Limit Comparison for Selected Jurisdictions

Bleached kraft pulp mill source emission limit guidelines and permits comparison for selected jurisdictions for newer mills, or for major rebuilds representing Best Current Practice expressed at the Alberta standard conditons of 25°C, 101.325kPa and the reference oxygen conditions of the source indicated

Jurisdiction			**British Columbia**		**Ontario**		**Quebec**		**USA**		**European Union (c)**		**Sweden (e)**		**Finland (d)**			**World Bank**	
Basis			Draft Guidelines 1995		1990 Guidelines						IPPC-BAT								
Source	Pollutant	Units (a, b)	Value	Averaging time	Value	Averaging time	Value	Average, Frequency	Value	Averaging time	Annual Average	Daily Average	Annual Average	Monthly Average	Annual Average	Monthly Average	Daily Max	Annual Average	Value
Recovery Boiler corrected to 8% O2 by volume dry	PM	mg/SDm^3	49				100		33 (p)			22 - 37		40-66			40		
	TRS	mg as H_2S/SDm^3	9.8	1-h			7.0		7.0 (q)	12-h		6.6		7		8.4			
	NO_x	mg NO_2/SDm^3	236	1-h								60 - 89				159			
	SO_2	mg as S/SDm^3	128	24-h								3.7 - 7.4				79			
Dissolving Tank	PM	g/tBLS	60	1-h					60 (p)										
	TRS	g as H_2S/tBLS	8.4	12-h			16		16 (q)										
Lime Kiln corrected to 10% O2 by volume dry	PM	mg/SDm^3	79	1-h			127		23 (p)			19 - 31		38-157			40		
	TRS	mg as H_2S/SDm^3	11	1-h			11.8		11 (q)	12-h		9.4		33		14			
	NO_x	mg NO_2/SDm^3										63 - 126 (u)				336			
	SO_2	mg as S/SDm^3										1.6 - 9.4 (o)				134			
Power Boiler - Bark 7% O2 by volume dry	PM	mg/SDm^3	53 (l)		46 (m)		70 (i)		96 (t)			8.6 - 26		70-291					50.9 (s)
	NO_x	mg NO_2/SDm^3	258	1-h			(j)		229 (h)			161 - 268							662 (s)
	SO_2	mg as S/SDm^3	-	-			(k)		153 (r)			40 (v)							2,040 (s)
All sources (f)	PM	kg/ADt									0.2-0.5							0.5	
All sources (f,g)	Sulphur	kg S/ADt									0.3-0.6		0.4		0.4			0.6	
All sources (f)	TRS	kg S/ADt									0.1-0.2							0.2	
All sources (f)	NO_x	kg NO_x/ADt									1.0-1.5		1.3		1.5			2 (n)	

Notes:

a) In the Units column: All PM, TRS, NO_x and SO_2 values in the table are corrected to the O2 reference conditions that apply in Alberta. These are shown in the left hand column.
b) In the Units column: All emission limits converted to Alberta Standard (S) conditons of 25°C and 101.325kPa and Dry (D).
c) The EU has no specified % O2 reference level for the limits. Typical operating O2 levels are assumed of 3% O2 for the recovery boiler, 5% for the kiln and 7% for the power boiler.
d) Finland has an O2 reference condition of 6% by volume dry basis for all sources.
e) Sweden has no specified % O_2 reference level for the limits (with the exception of 10% CO_2 for the bark boiler, taken to be 10% O2 by volume dry basis).
f) In the Basis column: Millwide includes all sources both major and minor but exclude power boilers.
g) In the Basis column: The contributions of both TRS and SO2 are included in millwide sulphur from all sources.
h) US: The NSPS NOx emission limits only apply to the oil, coal or gas component of the fuel input. Shown is the approximate limit value for 50%/50% heat input of wood and oil.
Oil NOx of 0.30lb/MBtu. The NOx of the wood fuel is not included for purposes of calculating the mass emission, but does dilute the concentration.
i) Quebec: For new units >10MW thermal heat input.
j) Quebec: No limit for units firing > 50% wood, < 50% fossil fuel.
k) Quebec: The sulphur limit on oil is 1.5% by weight.
l) BC: Greater than 20MW(72GJ/h) thermal input, otherwise 127mg/SDm3.
m) Ontario: For > 200t as fired wood fuel per day, otherwise 83mg/SDm3, also requires 1s residence time at temperature >1000°C.
n) World Bank: Value show is for softwood pulping. Guideline for hardwood pulp of 1.5 kg S/ADt.
o) The EU: For an oil fired kiln with no NCG firing. No guideline for gas fired kiln.
p) US: Maximum Achievable Control Technology (MACT) standard.
q) US: New Source Performancce Standard (NSPS).
r) US: The NSPS SO2 emission limits only apply to the oil, coal or gas component of the fuel input. Shown is the approximate limit value for 50%/50% heat input of wood and oil.
Oil SOx of 0.20lb/MBtu. The SOx of the wood fuel is not included for purposes of calculating the mass emission, but does dilute the concentration.
s) World Bank: For small (heat input > 3 and <50MW) solid fuel fired boilers, but can be up to 150mg/NDm3 if justified by envnonmental assessment. For larger units, the 1998 Thermal Power Guidelines are to be used. New Guidelines are currently in preparation but not available yet. See Appendix B.
t) US: This is the NSPS Standard since the much more demanding MACT standard of 10.8g/GJ (28mg/S_{2}Dm3) has been withdrawn.
u) This is the value for oil firing; higher values are associated with gas firing.
v) This is sulphur from biofuel component of fuel fired. Other fuels have different emission factors.

APPENDIX B - Mill Processes, their Air Emissions and Controls

APPENDIX B - MILL PROCESSES, THEIR AIR EMISSIONS AND CONTROLS

B - 1 Introduction

To provide background information, this Appendix starts with a broad overview of the main manufacturing processes in the pulp and paper industry. Subsequently, the discussion focuses on kraft pulp manufacturing. There are a large number of variations of the basic processes; thus the descriptions are necessarily generic in nature. This presentation does not cover solid wood products manufacturing operations such as sawmilling, plywood and panelboard, nor coating, converting and printing

To produce paper, paperboard or other products, the wood is first pulped. Pulps may be made from wood chips, sawmill residues, logs, and recovered paper. Pulps can be produced through chemical or mechanical means or by a combination of both, and are generally bleached. Finally, the pulp is processed into paper, paperboard, or fluff pulp. Finished paper or paperboard is then shipped to end users, such as printers or other uses, or it undergoes further transformation in converting plants to become products such as cut sheets or corrugated containers and other products.

The pulp and paper mills and their locations in Alberta are:

- 4 Chemical pulp mills — Boyle, Grand Prairie, Hinton and Peace River
- 2 Mechanical pulp mills — Slave lake and Whitecourt
- 1 Newsprint mill — Whitecourt

Accordingly, the description of processes that follow are limited to those processes used by the Alberta mills in so far as they relate to emissions of PM, NO_x, SO_x, VOC, NH_3, and TRS.

The sequence of presentation in this section observes the convention of following the fibre line from wood handling to finished pulp, then following the black liquor from evaporation through recovery and ending up with recausticizing and lime kiln. The utilities which include the steam plant, power generation and water and effluent treatment follow last.

B - 2 Overview of Pulp and Paper Manufacturing

B - 2.1 Fibre Supply, Wood and Chip Handling and Storage

As there are currently no mills in Alberta making paper from purchased wood pulp or from recycled paper, the source of fibre is wood. Wood in the form of logs can be delivered directly from the forest or as chips that are produced as a by-product of sawmill and plywood mill operations. Depending on such factors as seasonal availability, storage area, and seasoning

requirements, wood is stored at the mill for up to several months. Logs are typically delivered with the bark on and have to be debarked before chipping and screening.

Particulate emissions from this source originate from chip handling and mobile equipment movements. Given the large area involved for many of these sources, no control is currently practical, other than the use of belt instead of pneumatic conveyors which diminish dust generation, and good engineering practice in design, such as, enclosing conveyor galleries. Means for VOC capture and treatment present practical problems and are not currently practiced.

B - 2.2 Chemical Pulp Manufacture

Chemical wood pulping involves cooking wood chips or sawdust in an aqueous solution of pulping chemicals, resulting in the separation of cellulose fibres from the wood by dissolving the lignin that binds the fibres together.

The principal chemical wood pulping processes currently in use are kraft, acid sulphite, and neutral sulphite semi-chemical. The four Alberta chemical pulp mills use the kraft process, which is the dominant chemical pulping process in use today for reasons that include a high degree of recovery of chemicals, its insensitivity to variations in wood conditions and wood species, and the valuable properties of the pulp produced. It will be some time before more recently developed pulping technologies such as Alcell, and Milox are widely used since they have yet to operate successfully at industrial scale.

Mill capacities: In the 15 year period from 1980 to 1995, the upper limit imposed by equipment design capacity of new single line kraft pulp mills doubled to about 1800 ADt/d (air dry metric tonnes per day), and today has more than doubled again to about 4800ADt/d. This latter throughput reflects the design capacity of the Rizhao mill in China which is currently in design and construction. Rizhao includes a single digester, and recovery boiler though much of the balance of the fibreline is in two lines because of the lack of equipment of sufficient size to handle this capacity in a single line arrangement.

Pulping: Wood chips are cooked at an elevated temperature and pressure with white liquor containing sodium hydroxide and sodium sulphide in digester vessels either in batch or continuous mode.

Bleaching: Bleaching imparts whiteness and certain desirable physical and chemical properties to the pulp. Bleaching in kraft pulping is carried out in a multistage lignin-removing process as compared with single- or two-stage lignin-bleaching methods used for mechanical and some semi-chemical pulps. In the industry in North America and Europe, the most common bleaching and brightening agents are chlorine dioxide, oxygen, caustic, sodium hypochlorite, and ozone.

Associated with the bleach plant, is the chemical preparation and storage area, which includes chlorine dioxide generation, and may include other chemical production such as air separation for oxygen production, but only rarely a chlor-alkali plant for chlorine and caustic production. The area provides storage for other chemicals such as hydrogen peroxide, sulphur dioxide, caustic and other chemicals.

As chlorine and chlorine dioxide emissions are primarily an occupational health issue and not part of the scope of this study and for which no benchmarking data is available, these processes will not be further discussed in this report.

***Evaporation* and Chemical Recovery**: The spent cooking liquor, called black liquor, which is removed in the process of digesting and washing the pulp is used as a source of chemicals to regenerate the white liquor for reuse in the digester. This involves evaporation of the water to the point where the solids concentration is high enough for the black liquor is able to support combustion. This material is fired in the recovery boiler, where the heat is captured in the form of high pressure steam. The chemicals emerge as smelt from the bottom of the furnace. The conversion of the smelt into white liquor takes place in the recausticizing department which involves calcining lime mud to quick lime, CaO.

The recovery boiler is one of the most costly single pieces of equipment in a mill and is often the bottleneck to mill production capacity increases.

In older direct contact evaporator (DCE) type recovery boilers, black liquor oxidation (BLOX) is needed to reduce odorous emissions. This system is only briefly mentioned here, as none of the Alberta kraft mills require a BLOX emission control system, all of the recovery boilers in the province being the more modern low odour type boilers.

The black liquor is reacted with air or oxygen to convert the sulphide to thiosulphate, which is a more stable form of sulphur compound. This curtails the amount of H_2S evolved when the oxidized liquor is concentrated in the flue gas of the recovery boiler by means of the cyclones or the cascade. This reduced the TRS emissions of these older type recovery boilers. However in air oxidation, there is the emission from the black liquor oxidation tank vent, consisting of large volumes of water saturated vent gases. They are normally released directly to atmosphere from the BLOX vent stack, but are sometimes ducted into the stacks of large boilers for better dispersion in the atmosphere.

The normal solution to this source problem during the 1980s and early 1990s was conversion to a low odour recovery boiler, or retirement of these which, by today's standards, are small to medium sized boilers. In many cases, one or more older recovery boilers have been replaced with a new, single, large, more thermally efficient, low odour unit which has allowed an increase in pulp production and assisted in the economic justification, as the energy savings alone are not normally sufficient.[66]

B - 2.3 Mechanical Pulp Manufacture

Mechanical pulping relies mainly on mechanical energy to convert wood to pulp. The processes comprise stone groundwood, refiner mechanical (RMP), thermomechanical (TMP), chemi-

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[66] Bruce, D.M., Barynin, J.A., *The Merits, Justification and Options for Recovery Boiler Low Odour Conversion Today*. CPPA Technical Section Conference, May1997

mechanical, and chemi-thermomechanical (CTMP). Only TMP and CTMP processes are used in Alberta mills.

In the TMP process, the chips are usually steamed under a pressure of 20-40 psi for two to four minutes prior to refining, and the refiners are operated under pressure.

In all mechanical pulping processes, VOC and other pollutants of concern are emitted from the grinders or refiners, and lesser amounts from chip washing and other vents. VOC emissions include a wide range of compounds, but are very wood species dependent.

B - 2.4 Paper and Paperboard Manufacture

A pulp and paper complex making paper as a final product with, in some cases, additional pulp for shipment, are called integrated mills. Paper mills operating on a stand-alone basis use purchased baled pulp for paper and paperboard making.

The paper machine converts the pulp suspension into paper. All paper machines consist of a wet-end or forming section, a press section, and a dryer section. Further operations, finishing and converting, yield a final product. Converting is often carried out in stand-alone plants located in the consuming districts.

There are no significant atmospheric emissions associated paper and board operations, though surveys by NCASI show there is some VOC emitted, particularly from coating operations. By far the most noticeable emission for the paper machine department is the e dryer vent. While environmentally insignificant, it is often misunderstood by the public due to its highly visible, low buoyancy wet plume.

B - 2.5 Steam and Power Supply

Pulp and paper is a very energy intensive process, requiring both thermal energy in the form of steam and power to drive equipment. Steam requirements are met with boilers and power can be either self-generated or purchased.

Steam Plant and Power Boilers: The steam plant with its one or more power boilers, and any recovery boilers, plus any purchased steam generated nearby by others, provides the steam to meet all the requirements of the mill. The steam plant power boiler can comprise a single boiler or multiple boilers of different types and capacities depending on the nature of the mill.

The addition of a hog fuel dryer using the heat in the boiler flue gas can dramatically reduce particulate emissions by improved combustion conditions.

Cogeneration is the simultaneous production of power and useful heat, such as steam, hot water, or hot air. Cogenerated power is several times more efficiently produced than conventional utility generation is capable of. Boiler based cogeneration has long been used in the pulp and

paper industry, but the use of combustion turbine-based cogeneration systems is now more common.

B - 2.6 Effluent Treatment and Fugitive and Other Sources

Effluent Treatment: Liquid effluent discharged from a mill of any type requires treatment before release to the receiving water or municipal sewer system. Depending on the characteristics of the untreated effluent and regulatory limitations, primary, secondary, and, in unusual circumstances, tertiary treatment may be required to reduce the impact of the treated effluent to acceptable levels.

Sludges collected are either land filled or burned along with bark in the power boiler.

Fugitive and Diffuse Miscellaneous Sources: Emissions originating from unpaved roads, material handling, pump seals, valve stems, and gaskets that are often widely dispersed within the mill, are of lesser significance than the major stack sources. As well, small vents or stacks from the pulp mill or paper machine plants, plant ventilation, emergency vents pulp and paper mill effluent sludge landfills and wood waste disposal piles are often grouped and considered as fugitive emission sources.

Emergency Venting: Emissions from emergency vents, such as overpressure relief, are not considered candidates for treatment because the emissions occur during rare upset conditions and are typically of brief duration. In modern mills during normal operations all significant odour sources of TRS are collected in the NCG systems.

B - 3 Kraft Pulping

B - 3.1 Pulping and washing

B - 3.1.1 Batch and continuous pulping

B - 3.1.1.1 Description of process

The digester system, which may be a batch or continuous process, is at the heart of the pulping process and generally comprises a digester and blow tank or similar vessel to receive the digested pulp. The fibres are separated from the wood mass by dissolving the lignin and part of the hemicellulose in white liquor which contains sodium hydroxide and sodium sulphide as active chemicals. The digestion process produces unbleached pulp, called brownstock, and weak black liquor. Weak black liquor is a solution of solubilized lignin, water, hydrolysis salts, and sulphonation products. After cooking is completed, which is determined when the desired residual lignin content is reached in the digester, the weak black liquor and pulp are discharged into a low-pressure vessel called a blow tank in older continuous digesters and batch digesters. Heat recovery from the blow tank gases is often part of the blow tank system. The pulp from the

blow tank may then enter a defibering or deknotting stage prior to pulp washing. In the case of the new continuous digesters, the pulp is discharged from a wash zone in the bottom of the digester to a washer and then to a storage tank.

Digester blow gas emissions differ between batch and continuous digesters. The batch digester releases gases periodically when the digester blows the digested chips into a blow tank; continuous digester emissions are released at a constant rate to a condenser. Thus, overall volumes of gases from continuous digesters are less than those from batch digesters. High-pressure gases from the batch blow tank are typically sent to a primary condenser and then to an accumulator.

Turpentine originating in the chips is generally recovered from digester relief gases particularly when resinous softwoods such as pine are pulped. Typically, the digester relief gases are vented to a condenser to reduce the gas moisture content and to a cyclone separator to remove any small wood chips or fines. The turpentine and water removed by the condenser are separated in a decanter. The turpentine, which is lighter than water, overflows from the decanter to a storage tank. The water removed from the decanter bottom overflow is combined with other process condensates for treatment, such as steam stripping. During the decanting process, HAPs are emitted through vents. Methanol is emitted from the turpentine decanter at a level similar to that from a decker or screen.

Tall oils are found in resinous softwoods and are recovered from the evaporation process soap skimmings using a tall oil reactor. Though significant HAP emissions are not expected from this step because it occurs after the weak black liquor has been stripped of volatiles in the evaporation process, estimates of VOC emissions are noted in the following section.

B - 3.1.1.2 Air emission sources

In older mills, the digester is the third most important source of odour in the kraft process. Black liquor combustion is first and weak black liquor evaporation is second. Gases from the digester contain organic sulphur compounds from reactions between components of the wood and the sulphide of the white liquor. These sulphur compounds have high odour potential and are collectively called Non-Condensable Gases, abbreviated NCG. They also contain turpentine, methanol and acetone, as well as displaced air. Therefore, VOC, TRS, and HAP emissions originate from this area.

The principal air emission sources from a continuous digester system are: the atmospheric pre-steaming chip bin; gases associated with the flashing of the extraction stream to produce re-usable steam; and the blow tank gases. When pulping softwoods in particular, vapours flashed from the extraction stream can be condensed to recover turpentine.

Blow gases from batch systems are normally vented to an accumulator or, in some older mills, a vapour sphere for collection between blows.

The wastewater produced by the digester, digester blow condensates, turpentine decanter underflows, and evaporator condensates is a potential if not actual source of possibly toxic air contaminants and HAPs in downstream processes. These emissions may occur where, after

stripping, these streams are re-used for lime mud washing, or treated in an effluent treatment system.

B - 3.1.1.3 Emission controls

There is little that can be done to alter the kraft pulping process that would significantly diminish or eliminate the generation of these gases. Virtually the only approach in use today is the installation of the external NCG systems which collect, condition and convey the gases to incineration.

In order to reduce air emissions, alternatives to the kraft pulping process that do not use sulphur compounds could be considered. Pulping technologies such as Alcell, Milox, Organocel, and Natural Pulping are organic solvent methods, though none currently operates successfully at industrial scale. However, while the use and presence of by-product sulphur compounds would be virtually eliminated, the organic solvent chemicals would still result in significant VOC and HAP generation and need for emission controls.

Collection and treatment of NCG from kraft pulping process sources for total reduced sulphur (TRS) emission control have been practiced in the pulp and paper industry for over fifty years. The early systems were installed to control TRS emissions from the main concentrated sources such as the digester and the multiple-effect evaporators which are major sources in terms of mass emission rate. However, the practice for recent mills has been expanded to include the condensate stripper column overheads, additional concentrated sources such as turpentine decanter vents, and many more minor dilute process sources including all those prior to oxygen delignification and any other process and tank vents where unoxidized black liquor is handled.

The initial experience with NCG burning in the 1970s, which was practiced almost exclusively on the West Coast, was varied but generally considered to be satisfactory. In the early 1980s, however, there were numerous explosions at US southern mills in the gas collection or burning systems. At many installations, the materials used in building these gas collection or incineration systems have failed prematurely. As a result of US state implemented TRS control programs which applied to fibrelines and recovery systems constructed or modified after September 24 1976, a large number of existing sources have been retrofitted with NCG collection and burning systems. More recently all existing mills have had to comply with MACT standards issued 15 April 1998 which has required CNCG systems by April 2001 and DNCG systems by April 2006.

There are necessarily three completely separate NCG systems, and in some older systems, there may be a fourth, a separate intermediate concentration NCG system. Two of the systems handle concentrated sources, and the third, dilute sources. Concentrated non condensable gas (CNCG) also sometimes called low volume high concentration (LVHC) systems are gas mixtures containing little or no air. Any significant amount of air in CNCG is unsafe because of the wide range of NCG concentrations in air mixtures that present the risk of explosion. One concentrated system collects the methanol-rich stream from the top of the stripper column called stripper overhead gases (SOG); the second consists of the remaining concentrated sources comprising primarily TRS but also some turpentine from the evaporator and digester areas. The motive power for concentrated systems is steam ejectors, rather than fans to reduce the chances of sparks and the risk of explosions.

The third system conveys the much larger volumes of dilute non condensable gas (DNCG) gases. DNCGs contain a much higher proportion of air such that operation is well below the lower explosive limit; the associated piping is therefore correspondingly larger and significantly more expensive than for the concentrated systems. These dilute mixtures are also sometimes called high volume low concentration (HVLC) NCG. The motive power for the dilute systems are fans as there is virtually no risk of explosion because of the high degree of dilution with air.

An example of a modern NCG collection and disposal system is presented schematically in Figure B - 1.

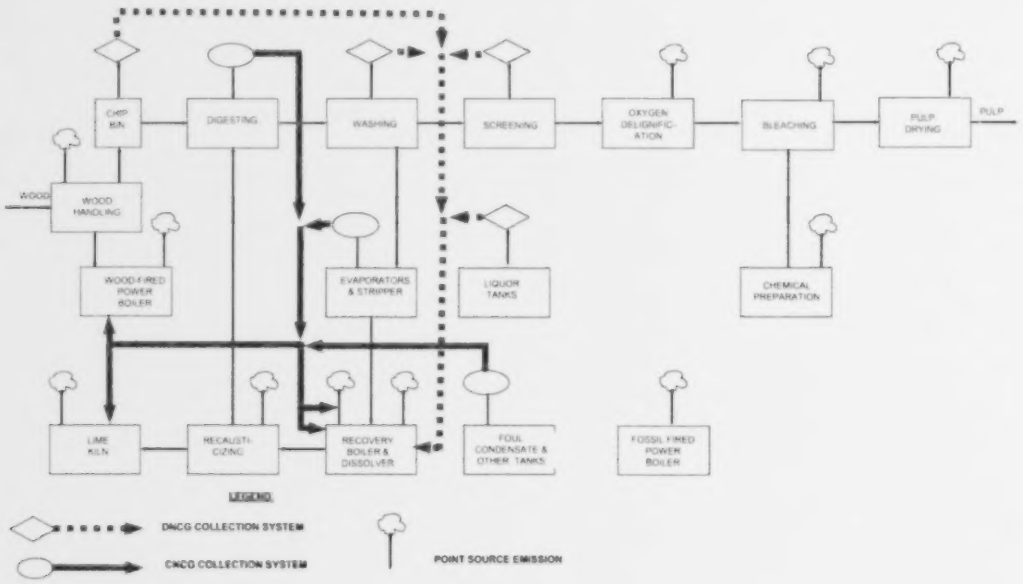

Figure B-1: Main Air Emission Sources and NCG Controls – Example

Until the late 1990s, most concentrated systems in mills were directed to the lime kiln for primary disposal. The power boiler may have been used as a back-up as a cost effective system. This approach ensures that part of the sulphur is captured by the lime and returned to the process, and the significant heat particularly in the stripper overhead gases results in a 5-10% or more reduction of fossil fuel use. However, operationally there may be the formation of rings (obstructing ridges) in the kiln when CNCGs are incinerated in the kiln, which may interfere with quality lime production.

In recent new mills commonly use dedicated incinerators for primary disposal, with backup in the lime kiln or the power boiler.

Since the mid-1980s, the dilute system is generally directed to the recovery boiler where it is introduced along with the tertiary air, but in some cases to the power as combustion air.

Dilute systems are not always provided with a back-up incineration point and are vented to atmosphere, though backup incineration is common in new mills. Where a backup is provided, the power boiler or a stand alone incinerator is sometimes used though the latter has the disadvantage of having a limited capability to handle large volumes. In relatively few cases, all collected NCG are directed to a stand alone incinerator where the DNCG provides the combustion air.

In the last 10 years, the firing of CNCG in recovery boilers has been introduced. In excess of 10 systems have been installed by one manufacturer alone. Both the stripper overheads and the other CNCGs are introduced through a special burner at the secondary air level. Key requirements of good CNCG applications for recovery boilers are high solids firing to create high furnace temperatures and the needed sodium fuming for good capture of sulphur in the furnace.

In the 1980s-90s, alkaline scrubbing liquids were sometimes used for CNCG treatment prior to incineration and result in reduced sulphur load to the incineration device which may be advantageous. Scrubbing media such as sodium hydroxide (NaOH) solution or white liquor, results in removal of the acidic sulphur compounds, such as H_2S and methyl mercaptan, and some of the organic sulphur compounds, such as dimethyl sulphide and dimethyl disulphide. Spent scrubbing liquor can be returned to the chemical makeup system. This practice has the disadvantage of increasing fugitive emissions from these areas and is not used in new mill designs.

Very occasionally scrubbing systems, some with proprietary scrubbing media, are used for short term solutions prior to TRS discharge to atmosphere.

B - 3.1.2 Washing

B - 3.1.2.1 Description of process

The washing system includes knot removal, screening, and washing to remove the solubilized lignin from the pulp prior to bleaching.

Knots are large fibre bundles or pieces of wood that were not fully broken down during digestion. They are generally defined as the fraction of pulp that is retained as wood chips or fibre bundles on a 3/8 inch perforated plate. Knots are removed from the pulp prior to washing and are either discarded as waste, burned, or returned to the digester for further digestion.

Two types of knotters are in current use. One type, an older design, is the open-top vibratory screen. The vibratory screen, which releases emissions directly to the atmosphere, is being phased out because of the large quantity of foam generated, which lowers the efficiency of the brownstock washer.

The second type of knotter consists of a totally enclosed, pressurized, cylindrical, perforated screen. A rotating foil in this type of knotter produces a series of vacuum and pressure pulses, which keep the perforations clean and reduces foam build up. Lower emissions are associated with this second type of knotter because it is an enclosed system.

The next step is screening to remove non-desirable fibres and dirt. The screens are generally of the type similar to the totally enclosed, pressurized knotter described previously. The screening systems may be close-coupled with higher motor power screens and no intermediate tankage and pumps, or standard configuration with lower power screens but pumps and intermediate tankage.

The purpose of brownstock washing is to remove weak black liquor from the pulp to recover sodium and sulphur as well as lignin and to avoid contamination during subsequent processing steps. The most common type of washer used in the industry today is the rotary vacuum washer. Other types of washers include diffusion washers, and the newer rotary pressure washers, horizontal belt washers, wash press, compact baffle, and dilution/extraction.

Washers differ according to the method used to separate black liquor from brownstock pulp. All washers require the addition of fresh or recycled water to rinse the pulp and recover the black liquor. The rinsed pulp is screened for oversize particles and thickened in a decker, where excess water is removed prior to oxygen delignification, bleaching, or storage. The weak black liquor is recovered in filtrate tanks and sent to the chemical recovery process.

Foam is formed when surface active agents such as resins and fatty acids, which are dissolved by the caustic cooking liquors, are aerated in the washing process. If soap is allowed to collect in the washing circuit, it will invariably end up on the fibres in the form of globules that are extremely hard to disperse in the washing process. Generally, defoaming is completed in the foam tank using centrifugal or mechanical force to break up the foamed mass. This force allows air trapped in the foam mass to vent to the atmosphere. The defoamed weak black liquor is typically piped to the chemical recovery process.

B - 3.1.2.2 Air emission sources

TRS, VOC and HAP emissions occur from the washing process as these compounds volatilize from the pulp and black liquor slurry. Vent streams from washers are considerably lower in temperature and therefore in moisture content than digester streams.

The strength and characteristics of the washer vent emissions vary with the type and geometry of enclosure used on the washer and the source of wash water, that is, whether cold water or process condensates. Rotary vacuum drum washers are typically hooded, but not fully enclosed and therefore require large volumes of air to capture and vent moisture and fugitive emissions and will have a dilute TRS, HAP and VOC concentration. Diffusion washers, horizontal belt washers or wash presses are enclosed so that vent streams from these washers have lower flow rates with higher contaminant concentrations.

A systematic measurement program for the brownstock washing area has been undertaken by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) for hazardous air pollutants and therefore includes a number of possibly CEPA Toxic air contaminants and is

summarized in reports that were published in 1995.[67] In general, emissions from all sources are highly variable depending on process conditions such as equipment, temperature, location in circuit, strength of the weak black liquor, and wood furnish.

B - 3.1.2.3 Emission controls

In older systems with vacuum washers, the hoods over the washers are vented through short stacks to atmosphere or are collected in a large capacity DNCG system.

A measure of in-process control is achieved in the selection of design and equipment. For instance, all newer mills install closed knotters and screens, and operate a closed screen room that eliminates continual discharge of brown water to the sewer, which vents to the DNCG system. The newest mills use presses instead of vacuum filters and, being closed devices, generate much smaller volumes of DNCG, which help to make incineration systems less capital intensive and ensures better recovery of the NCGs.

B - 3.1.3 Oxygen Delignification

B - 3.1.3.1 Description of process

Treatment of pulp with oxygen is used in some cases as a delignification step to remove further lignin from pulp prior to bleaching. Because the oxygen delignification stage effluent is compatible with the kraft chemical recovery process, the resulting effluent can be recycled to the evaporators and chemical recovery system, thereby reducing the organic load to the effluent treatment plant. The oxygen delignification stage consists of the reactor operating typically at 100°C and 5 atmospheres, a blow tank, and generally two washing stages.

B - 3.1.3.2 Air emission sources

The main sources are vents from the blow tank, the washers, and the associated tankage. Additional emissions may be associated with the use of evaporator condensates on the last post-oxygen washer. However, as the pulp is washed with clean hot water or stripped condensate, which are very cleanest process condensates, the emission levels are very low, and would consist mainly of methanol and carbon monoxide.

As part of a systematic measurement program for chemical pulp mills, oxygen delignification emissions have been studied by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) for VOC and for HAPs and therefore includes a number of possibly CEPA Toxic air contaminants. The results are summarized in reports that were published in 1995.[68] A total of 37 volatile organic compounds were measured in the emissions from 10 oxygen delignification systems.

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[67] NCASI, Compilation of 'Air Toxic' and Total Hydrocarbon Emission Data For Sources At Chemical Wood Pulp Mills, Technical Bulletin No. 701

[68] NCASI, Compilation of 'Air Toxic' and Total Hydrocarbon Emission Data For Sources At Chemical Wood Pulp Mills, Technical Bulletin No. 701

B - 3.1.3.3 Emission controls

Generally up to the early 1990s, no control technologies have been applied to oxygen delignification system vents to reduce air emissions other than to exhaust the steam vapours outside of any enclosed buildings. However, in the US EPA Cluster Rules for MACT I promulgated in 1998, existing system vents have required collection and treatment since April 2006, and all new system vents must have collection and treatment at start-up. These vapours are collected by the DNCG system with other pulping weak sources for collection and treatment in the DNCG system.

B - 3.2 Black Liquor Evaporation

B - 3.2.1 Evaporators

B - 3.2.1.1 Description of process

The first step in the recovery of chemicals is the removal of water from the dilute black liquor by evaporation. The weak black liquor collected from the pulp washing system is normally in the range of 12 -18% solids. This solids concentration must be increased to at least 65% solids by the removal of water for safe firing in the recovery boiler. Mainly two types of evaporators are used: the newer indirect type and the technically outdated Direct Contact Evaporator (DCE) type. Other types of evaporators in little use in Canada are the vapour-compression evaporator and the waste heat evaporator.

Indirect Contact Evaporators

The most common are the indirect contact type that achieves evaporation by means of heat exchangers. These are configured as multiple-effect evaporators, or less commonly, vapour recompression evaporator, that use the heat content in the water vapour to obtain additional evaporation, significantly reduce the net external energy requirement. The efficiency of energy usage in an evaporator system is expressed in terms of steam economy, defined as kg of water evaporated per kg of steam applied from an external source. Even though energy efficient systems are used, liquor evaporation and concentration consumes about 25% of the total steam needed for a bleached kraft pulp mill.

There has been considerable evolution in indirect evaporator systems over the years. The rising-film, long-tube-vertical (LTV) evaporator came into use on black liquor during the 1920s and 1930s, and rapidly became the standard system for concentrating black liquor. The LTV evaporator is still commonly found in use to evaporate black liquor. Prior to the 1970s, the almost universal practice in North America was to concentrate the liquor to about 50% solids in a five to seven effect LTV evaporator, and complete the concentration in a direct contact evaporator using recovery boiler flue gas as the heat source.

Since then indirect, steam heated multiple-effect evaporator systems have been used to accomplish all of the water evaporation required. The last three decades has also seen the

application of new types of evaporators to black liquor service. These include falling film evaporators of the plate type and the tube type, preheat-falling-rising types, forced circulation units, crystallizing evaporators and superconcentrators. These developments have resulted in the solids concentration as fired in the furnace to be increased from 65-70% typical of the 1980s to 75-85% and above in many of the latest designs where wood species make it practical.

As steam stripping of foul condensates has been introduced in the last three decades, these heavy users of steam have been thermally integrated into the evaporator plants to achieve the benefits of multiple effect thermal efficiency.

Direct Contact Evaporators

In direct contact evaporators, the liquor is brought into direct contact with hot combustion gases without any intervening heat transfer surface. Sensible heat is removed from the hot gas to supply the heat of vaporization for the water to evaporate from the liquor.

Until the late 1960s, direct contact evaporators were the only method used in North America to bring liquors up from about 50% solids to firing concentration. Two types of direct contact evaporators were commonly used: cascade evaporators and cyclones. There are many of these units still in use today in North America, but none in Alberta.

A cascade evaporator employs a rotating bundle of steel tubes which serve to pick up the liquor and move it through the hot flue gases. The cyclone evaporator is a vertical, cylindrical vessel with a conical bottom. Flue gas is admitted through a tangential inlet near the bottom and flows in a whirling, helical path to the top where it leaves through an outlet. Liquor to be evaporated is sprayed across the gas at the inlet.

Direct contact evaporators are nowadays an out-dated technology, although many remain in operation. The combination of stringent standards on odorous emissions and escalating fuel costs, together with the advantage of decoupling the final concentration step from the recovery boiler operation and the development of effective and reliable concentrators, has made direct contact evaporation obsolete.

B - 3.2.1.2 Air emission sources

The vapour that is boiled off when black liquor is evaporated is not pure water vapour, but contains some of the volatile constituents in the liquor. When the vapour is condensed these volatiles will either condense along with it and contaminate the condensate or remain as NCGs depending on their boiling point. For many decades now, environmental practice requires that both the most foul smelling part of the process condensates and NCGs be treated.

Air emissions result from the reuse of process condensates, the emission loading depending on the condensate segregation and stripper efficiency. Process condensates from the evaporation of the black liquor are segregated into those for direct use and others requiring stripping for removal of TRS and methanol contaminants prior to use.

Up until the mid-1980s, normal condensate segregation practice brings all condensates from the second effect to the last effect together, the blended stream being called combined condensates. Foul condensates, which are the process condensates from the surface condensers, and the cooler or last effects, are the most contaminated. To improve the quality of the combined condensates, it is common for the last effect to be baffled in order to split the condensates between the inlet and the outlet sections of the exchanger. The more contaminated back half is then combined with the foul condensates. The total foul condensate flow may represent 30-40% of the total evaporator process condensate flow and typically contains about 80% of the methanol and 98% of the TRS in the total process condensates.

In newer plate-type evaporators, enhanced segregation is achieved by baffling and removing a small stream of condensate in the last part of each of the early effects and directing these flows to the stripper as well. In this way the amount of foul condensates is reduced and the capture of TRS and BOD increased. All process condensate segregation techniques run the risk of upset by black liquor carryover resulting in condensate contamination which can cause foaming, and affect stripper performance.

In the case of direct contact evaporation in a recovery boiler, a major disadvantage is the problem of release of odorous gases directly into the recovery boiler flue gases discharged to atmosphere. The control of this source of odour can be partly overcome by oxidizing the black liquor before it enters the direct contact evaporator though a process called Black Liquor Oxidation.

B - 3.2.1.3 Emission controls

The evaporator plant NCGs are typically brought together in the evaporator hotwell or secondary condenser and picked up by the concentrated NCG system collecting the other dilute sources in the mill. The turpentine content of the evaporator NCGs varies depending upon the turpentine content of the black liquor being evaporated and the vent gas temperature. The reduced sulphur content of these gases has been reported to range from 0.25 to 5.25 kg/ADt, with an average value of 0.75 kg/ADt.

Emission discharges from direct contact evaporators are discussed in the recovery boiler section.

The atmospheric emissions may result from the use of evaporator condensates at the point of use such as washing brown stock and for causticizing. The resulting emissions are discussed in the sections dealing with those areas.

B - 3.2.2 Condensate Stripping

B - 3.2.2.1 Description of process

The kraft process produces two main condensate streams, one from the digester and the other from the evaporators. Both contain compounds that fall into two broad classes: BOD-producing compounds that contaminate water, and odorous compounds that generate air pollution. A general course of action is to segregate out the less contaminated condensates and re-use them

as-is. If the condensates are heavily contaminated (very foul) and therefore not re-usable without treatment, they are stripped of their contaminating compounds. Thus treated, the now very clean process condensates are commonly used for washing pulp in the brownstock circuit or as make-up to the causticizing circuit. As such, condensate stripping is in itself an air emission control system.

Stripping the contaminated condensates has proved an efficient and economical way of removing odour and reducing the BOD entering the sewer system. The two principal ways are air stripping and steam stripping. Air stripping tends to strip TRS from the condensates and collecting the resulting vent for incineration is not feasible because of the large volumes involved.

Steam stripping was first used in the 1950s and is today the normal approach to purifying contaminated kraft mill condensates. Steam stripping can be divided into two categories: TRS removal and BOD removal. Steam consumption to strip TRS only is relatively low: for a 90% TRS removal, amounts to about 2% of the condensate feed. To strip for BOD, which is largely methanol, requires a much lower pH and a high steam consumption: about 20% of the feed for a 90% BOD removal.

Steam stripping of condensates is performed in a stripping column using fresh steam. In the stripping column, the vapours rise through the column counter-current to the condensate; remaining vapours enter the primary condenser / preheater, where most of the vapour condenses. In retrofit situations, steam stripping columns are whenever possible tied into the with the evaporator plant to reduce steam usage. In new designs they are thermally integrated with the evaporator plant.

B - 3.2.2.2 Air emission sources

The main sources of emissions from the stripper are the overheads and the treated condensates.

The installation of a steam stripping column for effluent BOD removal will reduce TRS air emissions from the condensates. If TRS is removed, terpenes (x-pinene, x-terpineol) are removed simultaneously. Even if all the methanol is removed, phenols may not be entirely stripped. The steam stripper design and operating parameters that have the greatest effect on the removal performance of organic compounds are the number of trays (or height for packing) and the steam-to-feed ratio. Removal efficiency increases with each to a limit defined by the physical characteristics of the components.

The methanol and turpentine content of these gases depends upon the nature of the feed streams and the degree of stream stripping practiced. The feed stream methanol content can range from 2.5 to 10 kg/ADt pulp; and the turpentine content can range from <0.1 to 2 lb/ADT (<0.05 to 1 kg/ADt pulp). The reduced sulphur content of the stripper vent gases has been reported to range from <0.25 to 0.75 kg/ADt pulp in North America, and 1-2 kg/ADt of TRS in the Nordic countries.

Though air stripping systems were installed in the 1970s for odour control, these units have been entirely displaced by steam strippers, and are not considered further.

B - 3.2.2.3 Emission controls

At present, three approaches are used in designing the stripper vent gas handling systems. One design approach is to install condensers in the stripper exit gas line to condense the foul oil, turpentine, and some, or all, of the methanol present in the exit gas and provide for separate disposal.

A second and current design approach is to maintain the stripper off gases at an elevated temperature of 93-99°C and introduce them directly into the combustion device, thus burning the turpentine, foul oil and methanol contained in these gases.

A third approach is to further treat the rich stripper off gases in a separate methanol column to remove more water and achieve a methanol-rich product. This liquid methanol can be stored at ambient pressure that can be used as a support fuel when required. This more capital intensive approach is much used in Europe.

B - 3.3 Chemical Recovery

B - 3.3.1 Chemical Recovery Boiler

B - 3.3.1.1 Description of process

Kraft recovery boilers are of two types: the outdated direct contact evaporator type (DCE), and the newer low odour type, which uses indirect evaporation.

In the past the older technology DCE boiler was called a 'conventional' recovery boiler, but this a misnomer. In this report we have adopted the designation direct contact evaporator (DCE) type recovery boiler to distinguish it from the newer low odour recovery boiler, which uses non-direct contact evaporation. Low odour boilers were first introduced in the early 1970s.

In the period 1980 to1995, the largest recovery boiler capacity was in the order of 6.6 million lbDS/d, and today the size has more than doubled to about 14.0 million lbDS/d. Air emissions from the units per tonne throughput have decreased markedly by innovations of 3, 4 and more levels of combustion air, automatic port rodding, improved process control, and firing of black liquor solids at very high concentrations in the 80-85% solids range.

Industrial scale research is progressing slowly on black liquor gasification that would replace the recovery boiler entirely, with the aim of increasing thermal efficiency and power generation potential. Proven commercial operation however, is still perhaps a decade or more away.

The principal feature of the kraft process, apart from the delignification of wood to permit separation of the fibres, is the recovery of chemicals from the spent cooking liquor, and the recovery of energy from the waste organic chemicals. The recovery boiler is at the heart of the kraft recovery process and is the most expensive single equipment item in the pulp mill. It fulfills the following essential functions:

- Evaporates the remaining free water from the liquor as fired;
- Burns the organic constituents;
- Reduces oxidized sulphur forms to sulphide;
- Recovers inorganic chemicals in molten form;
- Conditions the products of combustion to minimize chemical carryover out of the furnace and air emissions; and
- Generates steam required for the process and other uses.

Recovery boilers have a number of features which set them apart from other boilers firing conventional fuels, which are:

- The fuel has a very high ash content and fouling tendency;
- Water must not come into contact with molten smelt to avoid the violent smelt/water explosions which can be very destructive and lead to loss of life;
- The potential exists for the production of odorous reduced sulphur gases by incomplete combustion and certain operating practices; and
- The potential for high fireside corrosion rates due to compounds of sulphur and chlorides.

The combustion and reduction processes within the boiler are complex, as it is a non-equilibrium process by nature, and not fully understood. The furnace environment is non-uniform. Regions of varying stoichiometry and temperature over time and space characterize the furnace volume; poor gas mixing increases the non-uniformity within each zone.

The main chemical reaction which occurs to recover the inorganic chemicals in the black liquor is the reduction of Na_2SO_4 to Na_2S:

$$Na_2SO_4 + 2C \rightarrow Na_2S + 2CO_2$$

This reaction occurs in the reducing zone at the bottom of the furnace. This is an endothermic, or heat absorbing reaction, which uses the very considerable energy released by the combustion of the organic carbon compounds to carbon dioxide and water. The organic carbon compounds are derived from the reaction of cooking liquor with lignin and hemicellulose.

Furnace and Boiler

The furnace above the smelt bed, but ahead of the main heat absorbing convective sections, comprises three distinct zones: a middle drying zone where the liquor is fired and loses free water, a reduction zone at the furnace bottom, and an oxidizing zone in the turbulent upper section. Water walls are of carbon steel continuously welded tangent tube or membrane

construction which created an air tight enclosure excepting spout, air port and other openings. Protection of these water walls was common in early furnaces using studded tubes and refractory. Today new furnaces use chromium alloy protection on the carbon steel water walls from the lower furnace to just above the tertiary air ports.

Even in older direct contact evaporator type recovery boilers, the furnace is relatively tall compared with the height of conventional fossil fuel boilers. This allows sufficient cooling of the gas by the water walls and residence time for burning of solid particles and completion of reactions. New low odour recovery boiler furnaces are significantly higher. The height is determined by the radiant heat transfer surface required to cool the gases to a suitably low temperature, typically in the 930°C range, but depending on fouling characteristics of the ash and carryover. The gases exit the furnace by passing around the bull nose, which protects the superheater from the heat radiation from the hearth.

Chemical Recovery Capacity

The amount of fuel that can be successfully fired in a chemical recovery furnace is limited by the heat release per unit area. The plan area of the lower furnace is generally set to achieve a liquor solids heat input of 2500-2700 kJ/m^2/s (800,000-850,000 Btu/h/ft^2), where the solids input is the product of the liquor mass flow rate and the higher heating value, normally both on a dry basis.

GUNS

In direct contact evaporator type recovery boilers, black liquor at 62-68% solids is fired as an aqueous spray from liquor guns into the lower part of the furnace in coarse droplets from a height of 3-5 m above the furnace floor. The liquor includes any makeup salt cake needed by the kraft liquor cycle and chemical ash as well as dust collected in the boiler hoppers and the precipitator. Combustion Engineering (now Alstom Power) and Ahlstrom have used from 6-16 guns, whereas Babcock and Wilcox and Tampella have used 1-4 large guns. Low odour boilers fire liquor at 65-80% and higher black liquor solids.

As liquor must not reach the smelt bed without drying and entrainment must be avoided, spray pattern optimization is critical. Determining factors are recovery boiler size, spray nozzle configuration, liquor temperature and pressure.

Combustion Air

Combustion air is introduced into the furnace through two, three, four or more sets of port openings in the furnace water walls designated from the bottom upwards as primary, secondary, tertiary, quartiary, etc.. Excess air is typically 10-15% of stoichiometric requirements, representing 1.9-2.3% oxygen by volume dry basis. The small and numerous primary air ports are located about 1 m above the hearth, or furnace floor and extend around the four walls and supply 50-65% of the total air in low velocity jets to the smelt bed.

Secondary air ports are generally located on all four walls but higher up the furnace walls. In the two level air system found on some older boilers, these ports supply the balance of the air and are located above the liquor guns.

In a three level air system, the secondary air is introduced below the liquor guns, 2-3 m above the hearth in larger, less numerous ports than the primary ports. The secondary jets supply about 30% of the total air. The secondary jets at higher pressure penetrate further and control the height and shape of the smelt bed, and supply air to burn the pyrolysis gases and CO evolving from the smelt bed. The tertiary air ports are higher still, 6-8 m above the hearth, and supply the remaining air, typically 20%, to complete the combustion.

Considerable success has been made in the last two decades in the analysis and understanding of gas flows and reactions in recovery boiler furnaces. Now computational fluid dynamics of the furnace region is routinely carried out to improve upper furnace gas mixing in order to reduce CO, TRS and NO_x.

Black Liquor Droplet Combustion

The liquor droplets, the size of which must be large enough to avoid entrainment in the rising furnace gases, but small enough to ensure reasonably fast drying and combustion, initially undergo a drying process. In drying, the liquor solids are converted to a tarry mass and the volume of the drop increases by a factor of three.

As heating continues, the drop undergoes pyrolysis, which produces volatile combustible gases through the degradation of the complex organic compounds comprising the black liquor. Lack of oxygen limits the pyrolysis gases burning in the immediate vicinity of the particle. The residual solid material remaining after black liquor has been completely pyrolized is referred to as char. The char particle has by now increased in size to about 10-30 times its original volume. The direct impact of this swelling is a dramatic increase in the reactivity and entrainability of the particle as its mass decreases simultaneously with the volume expansion. The majority of the char particles, consisting by this time of carbonaceous material and inorganic salts, drop to the bottom of the furnace in a dry and partially combusted state to form the smelt bed. The mounded smelt bed consists of a mixture of carbon and inorganic sodium chemicals rising 1-2 m above the furnace floor.

In the final stage of char combustion which is mostly carried out on the smelt bed, the organic carbon in the char is gasified to CO_2 and CO, while the inorganic material is converted to smelt containing Na_2S and Na_2CO_3.

Convection Section

As the heat transfer occurs principally by convection, the superheater, boiler and economizer and, in the many older boilers having them, the screen, comprise what is called the convective section. This section consisting of steam and water cooled tubes is located above the bull nose.

The gas temperature distribution through the heat transfer section will have a strong effect on the stickiness and tenacity of the tube deposits. The section initially presents very wide tube spacing in the passages receiving the hotter gases to accommodate deposits of solid particulate without plugging. Entrainment of smelt and char materials is a major cause of convection surface plugging.

Arrays of automatically traversing soot blowers operating generally in a continuous sequence one after another direct high pressure steam through nozzles to dislodge deposits from the superheater, the boiler, and the economizer.

Direct Contact Evaporator

The direct contact evaporator provides for flue gas to concentrate the black liquor in a cyclone or a cascade system in direct contact type recovery boilers. The low odour boiler uses an economizer of increased size to cool the flue gases prior to discharge, instead of the direct contact evaporator.

Carryover and Fume Generation

Ash or particulate entrained by the furnace exit gases consists of carryover and fume. Carryover is a mixture of partially or completely burned liquor black liquor particles that are swept away from the char bed by the upward furnace gas flow. Carryover has a composition similar to smelt. The rate of carryover is dramatically increased by increased recovery boiler load.

Fume results from the condensation of sodium and potassium compounds which are generated in the furnace. Sodium and potassium compounds dissociate at the 900-1100°C temperatures in the lower furnace and these metals react at very high efficiency with the SO_2 to form Na_2SO_4. The fume forms higher in the furnace condensing to very fine submicron dust of Na_2SO_4, Na_2CO_3, and other sodium and potassium salts. The fume is swept out of the furnace where it is captured by the downstream gas cleaning equipment, typically an electrostatic precipitator.

The characteristically high entrained particulate of recovery furnaces and the relatively low ash softening temperature of the sodium and potassium salts causes continuous deposition and fouling on the external tube surfaces. Melting temperatures for pure Na_2SO_4, Na_2CO_3 and NaCl are 851, 800 and 884°C respectively, but mixtures of these soften at a temperature 175-260°C lower, with potassium reducing the temperature another 100°C or so, to reach levels of about 560°C. The temperature/carryover relationship for black liquor inorganic carryover will always result on some fouling of the convective section tube surfaces. Carryover constitutes the majority of the material which causes fouling and plugging of the superheater and boiler bank.

Sulphur Release and Capture

Sulphur contained in the fume, SO_2 and H_2S represent nearly one-third of the sulphur entering the boiler. All of this material originates as reduced sulphur compounds in the lower furnace. Most of it reacts with oxygen to form SO_2 and SO_3. Much of these sulphur oxides react with

volatized sodium to form Na_2SO_4. The TRS, consisting of almost entirely H_2S in the stack gas, is the sulphur which was not oxidized in the furnace.

As black liquor contains 20% Na and 3-5% sulphur by weight, distributed among many different organic and inorganic compounds, there is more than enough sodium present to tie up all the sulphur.

B - 3.3.1.2 Air emissions

Ammonia Emissions

Virtually all of the NH_3 formed during devolatilization of black liquor droplet nitrogen is oxidized to NO or reduced to N_2. However, small amounts of ammonia (NH_3) could potentially escape unreacted. There is some limited evidence suggesting NH_3 is present in the flue gas as it exits the upper furnace. Control strategies are not presented due to lack of information.

Carbon Monoxide

Carbon monoxide is a product of incomplete combustion in the furnace, resulting from low sufficient excess air and poor furnace gas mixing in the upper zone of the furnace. CO will also be increased when firing black liquor at low solids concentration and when the boiler is at part load.

The rates of CO, NO_x, SO_2 and TRS emissions from the recovery furnace are all interrelated. One manifestation of the interrelationship is that all four emissions can not simultaneously be controlled to low levels. There is a well-known close correlation between CO and TRS as both reflect the degree of completion of combustion. Some evidence indicates that as NO_x increases, CO decreases and vice-versa. Only a weak association exists between CO and SO_2.

The variability of CO is due to disturbances in the lower furnace where it is formed. CO below 400 ppm_{DV} exhibits a very random behaviour, which is virtually impossible to control to much lower levels for any extended time.

Nitrogen Oxides

NO_x emissions from black liquor recovery boilers are low compared with those from fossil fuel fired boilers due to the lower combustion zone temperatures and the air staging that is an inherent part of the design. Air staging refers to the progressive introduction in the direction of the gas flow of combustion air. This is required to provide the necessary reducing conditions in the lower furnace while allowing the completion of combustion in the upper furnace.

Because of low furnace temperatures relative to fossil fuel fired boilers, fuel NO_x is the predominant NO_x formation pathway, though high localized temperatures such as over the char bed or above the secondary air ports may produce some thermal NO_x. Fuel NOx formation is related to black liquor nitrogen content, which can range from 0.05 to 0.25% of the liquor solids content.

Temperature governs the amount of thermal NOx formed, although it may also influence the amount of fuel NOx generated. NO amounts are 20 to 30 times higher than NO_2 amounts, although standard practice is to report NO + NO_2 emissions as NOx using the molecular weight of NO_2 when reporting mass emission rates. Stack gas NOx concentrations are normally in the range of 50 to 100 ppm, with higher mean values for NDCE furnaces versus DCE units. Other factors such as liquor solids content and furnace load also affect NO_x formation. However, this is most likely the result of simultaneous changes in excess air and its distribution among the levels.

As mentioned in the preceding section on CO, the emission rates of NO_x, CO, SO_2 and TRS from the recovery furnace are all interrelated.

Particulate

Entrained particulate or ash consists of carryover and fume. About 6-10% by weight of the incoming black liquor dry solids leaves the furnace as entrained particulate.

Carryover consists of char particles and black liquor droplets. The particle size is relatively large, ranging from 5-100 μm, with a composition similar to smelt. The rate of carryover is dramatically affected by the recovery boiler load. One author suggests increases of 70% in particulate carryover at 110% of maximum continuous rating (MCR) or 100% of boiler nameplate rating, and corresponding decreases of 30% at 90% MCR.

The fume consists of Na_2SO_4 and Na_2CO_3 and sodium and potassium salts. It is generated due to the high temperatures in the lower furnace which control the fuming rate. The condensed fume is of 0.25-1 μm particles. Since the fume reacts at very high efficiency with the SO_2 to form Na_2SO_4, a rate of fuming just sufficient to capture the sulphur released during combustion is another objective in the combustion process.

One of the advantages of a DCE is the 20-40% reduction of particulate concentration entering the emission control equipment.

Sulphur Oxides

SO_2 emissions arise from the oxidation of H_2S and TRS gases released in the lower furnace. The level of SO_2 emission formation is dependent on the sulphur content or sulphidity of the liquor fired. As the amount of sodium fume available to tie up the sulphur depends on the lower furnace temperature, the liquor heating value, the primary air temperature, boiler load, auxiliary fuel use, and furnace design are all determining parameters in the quantity of SO_2 emissions leaving the furnace.

The use of high solids firing (above 75%) in the newer recovery boilers results in virtually all the SO_2 generated in the furnace is captured by the increased amount of sodium fume formed released in the hotter lower furnace. For these units, SO_2 emission concentrations are a fraction of what they were a decade ago.

In older low odour recovery boilers firing solids in the 68-74% range, SO_2 emission concentrations are characterized by a high degree of random variation. In the even older direct contact evaporator type recovery boilers, tests show that about 75% of the SO_2 and nearly all of the SO_3 leaving the furnace is absorbed by contact with the black liquor in the direct contact evaporator.

OTHER SULPHUR GASES INCLUDING TRS

The TRS initially generated in the furnace depends on the liquor sulphidity and on whether the black liquor has been previously oxidized. TRS leaving the furnace is a product of incomplete combustion, and is aggravated by local pockets of insufficient excess air and poor furnace gas mixing in the upper zone of the furnace. There is a clear linkage between TRS and CO as both reflect the degree of completion of combustion. The affinity of oxygen for TRS is much more than for CO and this is reflected in the low variability of TRS compared with CO. TRS excursions are due to furnace disturbances. The TRS levels are generally two orders of magnitude less than that of CO, reflecting the reactivity of the gases and the quantities of inputs.

As already mentioned in connection with other emissions, the rates of TRS, CO, NO_x, and SO_2 emissions from the recovery furnace are all interrelated, therefore all four emissions can not simultaneously be controlled to low levels by combustion process manipulation.

In direct contact evaporator type recovery boilers, the stripping of H_2S from the black liquor in the DCE due to the acidification of the liquor by the CO_2 and SO_2 in the flue gas is normally the dominant source of TRS in the stack emissions, and has the potential of liberating substantial amounts of H_2S. H_2S is released from the hydrolysed form of Na_2S, sodium hydrosulphide, as the pH is lowered. Gas-liquid contact causes absorption of the flue gas CO_2 tending to reduce pH, which should be above 12. Emission control requires a high black liquor oxidation efficiency to reduce Na_2S to
0.10 g/L or less in the strong black liquor entering the direct contact evaporator. Under certain conditions with an effective oxidation of strong black liquor, H_2S can be absorbed from the recovery boiler flue gas across the direct contact evaporator, leading to a reduction of emission levels below that of the furnace. A very few DCE-type recovery boilers operate with extremely low TRS levels, one at Canton, NC, having a permit limit value of $5ppm_{DV}$ at 8% oxygen, though wood species and process normally prevent reliable compliance for such low concentrations.

In the case of heavily overloaded recovery furnaces, carbonyl sulphide can be formed. Though this gas is odourless and not a component of TRS, it is oxidized in most TRS continuous emission monitoring equipment, and is therefore included in the TRS measurement.

Volatile Organic Compounds

There are two main sources of volatile organic compound emissions in direct contact evaporator recovery boilers. One source is the pyrolysis gases that evolve during the drying and heating of black liquor solids, but which have not been fully oxidized in the upper furnace, at the level of the upper air windbox. The second source of VOC is the direct contact evaporator where VOC compounds are stripped from the black liquor into the gas phase. The VOC compounds in black

liquor are similar to those found in foul condensates, namely terpenes, organic sulphides (methyl mercaptan, dimethyl sulphide, and dimethyl disulphide), acetone, ethanol and phenolics. The susceptibility to stripping reflects their relative volatility.

B - 3.3.1.3 Air emission estimates and control strategies

Carbon Monoxide

Emission data for the old technology direct contact evaporator recovery boilers are available from numerous sources and range widely from about 50 - 2000ppm$_{DV}$ at 8% O_2. The mean values of tests and CEM data vary widely from one unit to another.

For low odour recovery boilers, CO emission results from tests done in the early 1980s have been reported as 460-2050 ppm$_{DV}$ at 8% O_2, while more recent tests based on CEM data gives average values of 200 for softwood and 160 for hardwood expressed as ppm$_{DV}$ at 8% O_2.

With continuous emission monitoring equipment, it has been possible to show that the CO concentration has wide variability characteristic of stochastic or random processes. Data collected during a period of stable boiler and mill operation show the marked effect of averaging time on emission concentration of the source. The degree of randomness or scatter of CO concentrations appears to be higher than that of NO_x, but less than that of SO_x.

Both direct contact evaporator and low odour type recovery boilers control carbon monoxide emissions by in-process rather than external means. In general, CO emissions are minimized by control of excess air and by ensuring good mixing in the upper furnace volume, particularly at the highest level of combustion air using dampers, large air ports and adequate pressure for good jet penetration. Boiler controls must be adequate to control the excess air with adequate precision to accomplish the task.

Older furnace designs generally lack the modern air systems which make this objective feasible. Thus whether a direct contact evaporator type or older low odour type recovery boiler, combustion air upgrading is always included in a boiler modernization today to improve efficiency, and to reduce not only CO but TRS and VOC emissions as well. Achieving the minimum practical level of excess air in the flue gas is based on continuous CO and TRS measurements. If there is a reduction in excess air below that level to control CO emissions, it will be accompanied by an increase in TRS, NO_x and most likely SO_2, emissions, due to the interdependence among them.

Research and development of computational fluid dynamic simulation undertaken in the last decade, notably at the University of British Columbia, has resulted in improved understanding of the combustion air jets, their interaction with the furnace gases and impact on performance and air emissions.[69]

[69] Salcudean, M., Gartshore, I., and Gorog, P., *Computational Fluid Dynamics(CFD): A Tool for Simulating Pulp and Paper Processes*. TAPPI 2001 Engineering/Finishing &Converting Conference and

Nitrogen Oxides

NO_x emission data available for direct contact evaporator recovery boilers range from 29 to 105, and average 58 ppm_{DV} at 8% O_2. For low odour recovery boilers, data range from 54 to 125, and average 74 ppm_{DV} at 8% O_2, based on four continuous emission monitoring equipped units and nine permit limits.

CEM data shows that the NO_x concentration has fairly wide variability though much less so than CO and SO_2.

As liquor nitrogen is not a controllable parameter, NO_x control measures are:

- Minimizing excess air; and
- Combustion air staging.

Some data on the impact of high solids firing on NO_x emissions supports the expectation of increased NO_x as percent solids increases. Results from one source showed 55-67 ppm_{DV} However, contrasting with these results, Finnish tests from 7 furnaces reported a decade ago show, if anything, a decreasing NO_x concentration with increasing solids. One boiler has a NO_x emission of 40 ppm_{DV} for all firing from 60 to 80% solids.

The contradictory results may be the result of differing degrees of air staging and distribution which in new designs are at three and four levels up the furnace, and can decrease peak temperatures.

Selective non-catalytic reduction (SNCR) which uses the injection of urea or ammonia into a high temperature location in the furnace is not considered technologically feasible for recovery boiler applications because of the risk of disrupting the complex chemistry of the unit. A related process, selective catalytic reduction involves the use of catalysts in the hot gas stream. Though considered in some jurisdictions, concern that the catalyst would be fouled by contaminants in the gas stream has resulted in no installations in the industry.

Both wet and dry scrubbing for NO_x and SO_2 removal for the utility power industry have been developed, and wet scrubbing reduced NO_x from 400 - 600 ppm to 1-10 ppm using a proprietary chemical, though applicability to recovery boilers has not been reviewed.

When fossil fuels are co-fired with black liquor fuel, the emission factors applicable to each fuel are assumed to apply, and the individual contributions summed to estimate the total emission. NO_x emissions for standard burners average 100, 170, and 470 ng/J (133, 223, 578 ppm_{DV} at 8% O_2), for gas, oil and pulverized bituminous coal burners respectively. For low NO_x burners with staged combustion or flue gas recirculation, the corresponding values are 60, 110, and 260 ng/J (80, 144, 319 ppm_{DV} at 8% O_2). More advanced technology low NO_x burners in fossil fuel only fired full size units report NO_x levels down to 13 and 34 ng/J (17 and 45 ppm_{DV} at 8% O_2) for

Trade, San Antonio, Texas, Dec. 2-6, 2001.

gas and oil firing based on controlled test results. With flue gas recirculation and low NO_x burners the lowest levels reported are 9 and 13 ng/J (11 and 17 ppm_{DV} at 8% O_2) for gas and oil firing, though this technology has not been applied to recovery boilers, since operationally, fossil fuel is generally used for start-up and constant use is to be avoided.

Particulate Matter

This emission contaminant is always controlled, since uncontrolled emissions are very high. Entering the electrostatic precipitator (leaving direct contact evaporator) PM is about 11,000 mg/SDm^3 at 8% O_2, whereas for low odour recovery boilers is of the order of 14,000-24,000 mg/SDm^3 at 8% O_2.

Carryover particulate leaving the furnace and boiler can be controlled by furnace size and by proper design and operation of the firing and combustion air systems. The rate of carryover is dramatically affected by the recovery boiler load. One author suggests increases in particulate loadings of 70% at 110% of maximum continuous rating (MCR) or 100% of boiler nameplate rating, and corresponding decreases of 30% at 90% of MCR as compared with 100% MCR.

The release of particulate fume of sodium and potassium salts is controlled by the temperatures in the lower furnace. Since the fume reacts at very high efficiency with the SO_2, a rate of fuming just sufficient to capture the sulphur released during combustion is required to control TRS and SO_2. However, normal control of the highly dynamic nature of recovery boiler operations is directed towards controlling TRS, SO_2, NO_x and CO, as particulate is controlled by external means, normally in an electrostatic precipitator.

The dry type electrostatic precipitator is the most common type of particulate control device on existing and new low odour recovery boilers. The precipitators used on older technology direct contact evaporator type recovery boilers had dry collector plates with wet bottoms which allowed the collected dust to fall directly into black liquor circulating beneath the collecting plates. These are to be distinguished from wet type electrostatic precipitators used in some power boilers, where dust is removed by irrigating the collection plates with water. Most wet bottom type precipitators have by now been replaced by dry type electrostatic precipitators.

Sulphur Oxides

Emission data for 21 direct contact evaporator recovery boilers range from 1-395, and average 75 ppm_{DV} at 8% O_2, while that for 13 low odour recovery boilers range from 1 to 1990, and average 97 ppm_{DV} at 8% O_2. It is noteworthy that SO_2 emissions have a high degree of random variability associated with them. By way of illustration, the 1 hour average SO_2 concentration can be 3.5 times the 30 day long term average.

With the introduction of high solids firing, in-process controls are nearly universally accepted as the most desirable control approach for SO_2 in existing recovery boilers. Where upgrading an existing boiler to high solids firing is impractical, or where the concentration is to be controlled to levels lower than that attainable by high solids firing, wet or wet-dry scrubbing of the flue gas can be used. It is noteworthy that because of the importance of the acid rain issue in the

Scandinavian countries, and requirements for heating water in older mills integrated with paper mills, about 26 of the 47 recovery boilers in 1992 were fitted with scrubbers which reduce SO_2. These scrubbers reduce particulate emissions as well.

Control of SO_2 in direct contact evaporator type recovery boilers is achieved by attention to the furnace operation to maximize the lower furnace temperature by maintaining high load and combustion air temperature, and operating at the lowest sulphidity consistent with pulp quality and good economics. The scrubbing action of the direct contact evaporator will reduce this emission further. Based on a reference applicable to older furnaces where SO_2 levels are very elevated, this will allow up to 75% removal of the SO_2 by contact with the black liquor, and nearly all of the SO_3.

Increasing the percentage of solids in the black liquor as fired from 65-68% to 72-76% in the 1980s and 78-82% in the 1990s has been an on-going trend in recovery boiler design. Since the late 1980s particularly, improved black liquor concentrators and the introduction of liquor heat treating to reduce liquor viscosity have made higher solids concentration liquor available for firing. The benefits are an increase in thermal efficiency and steam generation, a dramatic reduction in SO_2 and TRS, and reduced gas velocities and convection section plugging potential.

In the upgrade of an existing older technology DCE-type recovery boiler, the costs for increasing the liquor concentration to 74-78% would be included in the low odour conversion costs. This is discussed in detail in the following section on TRS mission control.

The emission reduction benefits of high solids firing have been extensively researched and indicate an exponential increase in sodium fume generation with increasing temperature in the lower furnace which ties up the sulphur compounds above about 75% solids.

For an older type low odour recovery boiler firing 65-68% solids, upgrading to high solids firing would involve adding extra surface to the concentrators for the increased evaporation load as well as off line heat exchange surface in wash mode to compensate for the increased fouling. Typical equipment additions for high solids firing might include one four body concentrator effect, an indirect-type liquor heating and conditioning equipment, and additional soot blowers.

Total Reduced Sulphur

Emission data for 3 DCE recovery boilers provides a range of 8-80 ppm_{DV} TRS as H_2S at 8% O_2 based on CEM measurement data while that for low odour recovery boilers was 4.3 ppm_{DV} at 8% O_2.

Control of TRS in DCE recovery boilers is a two step process. The first is the control of the furnace TRS emissions by attention to the furnace operation to provide an adequate level of excess air and optimal distribution of combustion among the wind boxes. The second is control of the TRS emissions contributed by the direct contact evaporator. This requires the maintenance of a high alkalinity fully oxidized strong black liquor feed to the direct contact evaporator to prevent additional H_2S being released.

There is not much that can be done to an existing older DCE recovery boilers to reduce TRS levels to the very low 1-3 ppm_{DV} long term average levels associated with the latest recovery units. Such emission levels would require a major rebuild involving conversion to low odour operation which eliminates the direct contact evaporator and raises the firing solids. The economic justification of low odour conversions is increased steam generation through higher boiler efficiency.

The low odour conversion involves the addition of steam heated indirect type black liquor concentrators, increasing the size of the boiler economizer, and upgrading the precipitator due to the additional volume to be handled with a higher inlet dust loading. With the site congestion typical of many existing older mills, the extensive structural work, and the four weeks or more lost production, the investment is hard to justify on a return on investment basis. A more serious flaw is that strategically a low odour conversion is difficult to justify economically in a high pulp manufacturing cost country like Canada where competitiveness is only maintained by production at the largest scale possible.

A number of wet scrubber technologies were developed in the early 1970s for the reduction of emissions from direct contact evaporator type recovery boilers. The emissions of concern at the time were principally odour, but also particulate in some instances where electrostatic precipitator performance was compromised by maintenance difficulties related to corrosion. Odour emissions arise from relatively high TRS emissions, even with good black liquor oxidation, and SO_2. In response to these problems, wet scrubber technologies were adapted as outlined below:

The Flakt Modo scrubber is an example of a wet scrubber adapted for emission control, though the justification originally was the production of hot water. The installation is made downstream of the precipitator and heat recovery is available in the form of heated water. The scrubber is divided into several sections: chloride zone, particulate zone, SO_2 zone, a section for TRS removal and a heat recovery section producing nearly clean water. Of Swedish design and first operated in 1963, many scrubbers of this type were installed in the 1970s as the scrubber found particular application with direct contact evaporator type recovery boilers in older mills with a high warm and hot water usage.

Removal rates are in excess of 98% for particulate. Removal rates for SO_2 of 80-90% are expected with calcium based solutions, and higher 90-95+% with caustic. TRS can be removed by adding a section using the Paprican activated carbon for more efficient TRS removal.

Another technology is the hybrid venturi/cross-flow type scrubber developed by Teller Environmental Systems Inc. has been used in a number of direct contact evaporator type recovery boilers since its introduction in the mid-1970s. The process uses a low pressure venturi scrubber to remove large particles, and alkaline absorption and oxidation system in a cross flow nucleation section to remove TRS, and a packed bed to remove small sub-micron particles by aggregation. Installations in Canada are at Elk Falls (BC), St Laurent Paperboard(QC), and St. Anne-Nakawic (NB).

A feature of wet scrubbers is that the exiting stack gases are very cool which leads to poor plume buoyancy and less effective dispersion from the stack.

In the early 1970s, PAPRICAN researchers developed a patented packed bed scrubbing process to remove TRS and particulate from the flue gases from direct contact evaporator type recovery boilers. This technology was subsequently licensed to several scrubber vendors, including Flakt and Teller Environmental Systems.

Volatile Organic Compounds

VOC emission data for six direct contact evaporator recovery boilers gives values of 105-180 ppm_{DV} as CH_4 at 8% O_2, while for low odour recovery boilers were 65-75 ppm_{DV} as CH_4 at 8% O_2.

For an existing unit, VOC are controlled in the same way as carbon monoxide emissions are controlled, that is, by control of excess air and ensuring good furnace mixing with a modern combustion air system providing good penetration at three, four or more levels.

B - 3.3.2 Smelt Dissolving Tank

B - 3.3.2.1 Description of process

Depending on the recovery boiler manufacturer, one or two smelt dissolving tanks are located under the furnace to receive the smelt decanted from the smelt bed. The smelt dissolving tank is an enclosed agitated tank with its own oversized vent stack. The shattering and violent reaction of the quenching smelt generates large volumes of steam and air emissions comprising particulate, TRS, SO_2, and other more minor emissions.

The presence of reduced sulphur compounds in the smelt, escape of gases from the recovery furnace into the smelt dissolving tank, and volatilization of contaminants in the scrubber water all are potential sources of TRS emissions. SO_2 emissions appear to originate from the oxidation of these gases. Measurements show that emissions also include some NO_x, which is thought to originate in the violent reaction of smelt and water, or from in-leakage from the furnace. VOC emissions from smelt tanks are found in the vent gases, and result from the use of process condensates as makeup water in the recausticizing plant.

B - 3.3.2.2 Air emission estimates and control strategies

Control technologies designed to reduce PM, TRS, SO_2 and other emissions are:

- Control the quality of clean / stripped condensates as scrubbing medium, so that contamination of the weak wash in the smelt dissolving tank with organics is avoided to reduce TRS and VOC generation.
- Mist elimination consisting of pads of fine wire mesh screen are used on older technology dissolving tanks to remove particulate matter and water droplets from the discharge, which coalesce on the wire. Water sprays help the collected material drain back to the dissolving

tank. The particulate removal efficiency of sprays and mesh pads is about 70-90%, or to about 1 to 0.53 kg/tDS.

- Chevron packing provides improved particulate removal efficiency when compared with mesh pads, or to about 0.08-0.13 kg/tDS.
- Packed bed scrubber can provide greater removal efficiency, but plugging problems can result, and some test data suggests a wide range of 0.06-0.33 kg/tDS.
- Dynamic scrubbers use nozzles, fans or venturis to thoroughly mix the gas and scrubbing liquid. Such positive mixing not available in the measures just described is needed to reliably attain less than 100 g/DS particulate emissions.

The dynamic scrubber also achieves TRS removal to 8g as H_2S/tDS using clean water, and SO_2 to about 80 g/tDS.

HAP emission controls were explored in a significant 1996 report, which looked at technical feasibility, performance and costs of options.[70] The conclusion of this analysis was that wet scrubbing with clean scrubbing medium provided the best approach to HAP control.

A common approach in the newest recovery boiler designs is the ducting of the smelt dissolving vent gases into the recovery boiler for incineration. It is estimated that about 10 are installed or about to be started up. First, the gases are conditioned by scrubbing as before for contaminant removal, cooling to remove water vapour and reheating prior to being introduced into the furnace combustion tertiary air windboxes.

B - 3.4 Causticizing and Lime Burning

B - 3.4.1 Causticizing

This mill area regenerates white liquor for use in the pulping process from the chemicals recovered in the green liquor from the dissolving tank and quick lime calcined in the kiln.

There are few sources of emissions of any type emitted from the causticizing area and all are small in terms of mass emission rate. One source is the particulate generated from the strong reaction of the lime with green liquor in the slaker. This reaction produces some steam which carries particulate matter with it as it is vented to atmosphere. Some form of water spray scrubbing for particulate emission control is generally provided before release.

A second type of emission are the more diffuse TRS emissions that result from the use of stripped or clean process condensates in the process. These TRS emissions have generally been considered to be insignificant. As well limited testing has revealed high concentrations of

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[70] USEPA, *Technical Support Document - Chemical Recovery Combustion Sources at Kraft and Soda Pulp Mills*. Oct 1996

ammonia above slakers, causticizers and other causticizing area equipment. However, due to the small gas flow rates, actual mass emissions of NH_3 are fairly small[71].

B - 3.4.2 Lime Burning

B - 3.4.2.1 Description of process

The causticizing process produces white liquor from green liquor, which it does by consuming quick lime while producing lime mud (principally $CaCO_3$) and caustic soda. Lime reburning converts the $CaCO_3$ back into CaO for reuse in the causticizing process and requires the high temperatures and residence time provided by a kiln or calciner Rotary lime kilns are widely used to reburn lime, though a few fluidized bed calciners are found in use as well. Burning lime requires a significant quantity of heat, much of it at high temperature to complete the calcination. Because these high temperatures are most easily attained with fossil fuel, gas or oil are virtually the only fuels used. There are several kilns in Sweden that still use suspension-fired dried pulverized wood waste, though more were operating in the 1980s.

Rotary lime kilns are large refractory lined steel cylinders which are slightly inclined from the horizontal and are slowly rotated. Lime mud is introduced at the higher end and it slowly makes its way to the lower discharge end due to the inclination and rotation. A burner is installed at the discharge end of the kiln. Heat transfer from this flame and the hot combustion gases that flow up the kiln dries, heats, and calcines the counter-flowing lime solids.

All modern kilns are being offered with product coolers which preheat combustion air and improve the energy efficiency of the kilns. A recent alternative to the standard rotary lime kiln is the use of a kiln of shorter length, a lime mud dryer and product coolers. The lime mud dryer and product coolers can also be retrofitted to older kilns to increase kiln capacity.

B - 3.4.2.2 Air emission sources and control strategies

The burner combustion gases comprising CO, CO_2, N_2, SO_2, NO_x, water vapour, passing through the calciner carry particulate calcium and sodium compounds, TRS, VOC, and HAPs to the discharge stack.

Carbon Monoxide

Carbon monoxide is a product of incomplete combustion of the fuel in the kiln, resulting from insufficient excess air and possibly poor gas mixing in the burner combustion zone.

Averages of 1h carbon monoxide emission data in 1980 for several kilns were below 20 ppm_{DV} more than 70% of the time, with median values in the range of 5-15 ppm_{DV} at 10% O_2) for kilns with oxygen monitors.

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[71] *NCASI Environmental Resource Handbook for Pulp and Paper Mills* 6-39, Chapter 6: Chemical Recovery Processes © 2002 National Council for Air and Stream Improvement *Last revised March 1, 2002.*

Carbon monoxide emissions may be minimized by appropriate control of burner excess air levels during combustion.

Carbon Dioxide

Carbon dioxide is a product of the fuel combustion and the calcining reaction where the $CaCO_3$ releases CO_2 in order to produce CaO. This gas is a greenhouse gas but is not an air contaminant in terms of affecting ambient air quality.

Nitrogen Oxides

The formation of NO_x is related to the nitrogen content of the fuel used and the flame temperature which is a function of burner design. Its formation in a lime kiln is mostly directly related to the need to attain a high flame temperature for good radiation to the bed of lime.

Data published for 14 lime kilns showed average NO_x of 112 ppm_{DV}, but a very wide range of 4 to 450 ppm_{DV}, all at 10% O_2. These results showed no significant difference between the NO_x emissions resulting from gas firing and oil-firing, though other data showed that gas firing results in somewhat higher NO_x discharges. In a Finnish survey NO_x concentrations varied from 30 up to 70 ppm.

As NO_x are typically not scrubbed out in any significant amount across a wet scrubber, the emissions may be assumed to be unaffected as to whether the particulate control device is a scrubber or an electrostatic precipitator. The impact on NO_x emissions due to NCG burning is also not expected to be significant as the percent heat input from NCGs is usually very small, and the combustibles in the NCGs typically have negligible nitrogen content. However, one survey showed that the combustion of NCGs seems to increase the NO_x some 30-40 ppm.

The lime kiln must be operated so that air supply to the kiln produces oxidizing conditions throughout. The burner must have a high flame temperature to make best use of fossil fuel, though peak temperatures are about 550°C less than that found in the burner of a cement kiln. These requirements severely limit the application of NO_x control techniques used in boiler applications such as minimizing excess air and staged combustion. As flame emissivity and therefore radiative heat transfer varies as the forth power of the absolute temperature, attempts to modify NO_x formation by adjusting the kiln running parameters, the flame shape, the air distribution and the excess oxygen, have not been very successful.

If the air supply is inadequate, emissions of TRS and CO from the kiln will become very high and excessive carbon deposits in the lime will occur. Flue gas recycle may be the most promising approach, however, extensive testing is required since the temperature profile would be altered and hence possibly the calcining efficiency. Neither SCR nor ammonia injection is likely to be satisfactory due to the high particulate loading. No kraft lime kilns are believed to be in operation using this technology.

Particulates

Dust loading leaving a lime kiln is related to two different mechanisms. The first is lime dust formation which depends on a properly configured lime kiln chain section, feed end design and a proper pelletizing process in the hot end of a kiln.

The second is alkali dust formation originating from alkali vapour which condenses to a very fine particle size below 10 μm when the flue gas cools on its way down the kiln. Poor lime mud washing results in increased sodium input to the kiln and higher dust formation, as does oil firing since an oil flame gives higher temperatures than a natural gas flame at the hot end of the kiln due to its better radiation properties, and thus increases the sodium volatilization from the lime. The amount of alkali vaporization can up to a certain level be controlled by a proper adjustment of flame shape and position because it is sensitive to the temperature profile of the kiln. Also the amount of sodium in the lime mud has some effect but usually this fume is always formed and it can be effectively removed from the flue gas with an electrostatic precipitator only because of its fine particulate size.

The wet scrubbing devices are usually placed following a mechanical cyclone collector used either for removal of the larger lime dust particles, as with lime kilns, or for predrying the lime mud for fluidized bed calciners. The principal wet scrubbing devices have been the impingement and venturi types, both of which were in common use before the advent of electrostatic precipitators.

The scrubber liquid discharge should be re-used in the process to capture the raw materials and to avoid transferring the air emissions to the water effluent. The scrubber discharge gas is colder and wetter than the discharge from an electrostatic precipitator and provides poorer plume dispersion.

Since the late 70s, electrostatic precipitators have been used in favour of wet scrubbers because of their cost effectiveness when very high particulate removal efficiencies are required. Electrostatic precipitators only control particulate emissions whereas wet scrubbers have the potential to be adapted to control other emission parameters as well, such as SO_2 and TRS. A precipitator, when properly sized, can achieve high removal efficiency even with the very fine alkali fume, and measurements have shown an emission level of 13-19 mg/SDm^3 at 10% O_2. Retrofitting may have additional problems associated such as discharge temperature which is higher in older kilns. Access and layout may also increase costs.

Sulphur Oxides

Sulphur dioxide has often been thought to be absorbed by the lime. However, this appears unlikely since, under normal conditions, the amount of calcium sulphate in reburned lime is small.

It appears from NCASI work that additional sulphur input to the lime kiln, beyond that from the sulphide content of washed lime mud, either in the form of residual fuel oil sulphur, petroleum

coke fuel, or TRS-containing NCGs, would not have a direct impact on the corresponding SO_2 emission levels.

Late 1980s Swedish measurements reported in a consultants internal report analyzes measurement data after control device indicate that 50% of the concentrations are below 11 ppm_{DV}, with approximately 90% of the kilns having values below 110 ppm_{DV}, which is comparable with NCASI data. It is noteworthy that there are a number of kilns that have substantially higher emissions into the 200-400 ppm_{DV} range.

If the high temperature neutralization reactions are not effective enough to lower the sulphur dioxide concentration in gases before the heating section, the sulphur dioxide rich flue gases come in contact with lime mud in the kiln section where the lime mud still contains sodium compounds on the particle surfaces. If the lime mud contains high amounts of sodium, 0.5-1.5% Na_2O, a severe ring formation can occur due to sodium sulphate formation in the bed.

Scrubbers are generally installed to reduce particulates and have not necessarily been optimized for SO_2 and TRS removal. Particulate removal requires high gas velocities which are not conducive to gas absorption. In Scandinavia, with the focus on acid rain, it seems to be more and more common to install an alkaline scrubbing stage after the electrostatic scrubber to adjust the SO_2 emission to the required level. SO_2 emission after such a system can be below 5 ppm and the dust emission 7 mg/SDm^3 at 10 % O^2.

Total Reduced Sulphur

The TRS emission consists mostly of H_2S, and may originate in two ways. If the fuel contains sulphur and the flame does not receive enough air, the combustion is substoichiometric and the flue gases will contain carbon monoxide and hydrogen sulphide.

The second way that TRS originates is from sodium sulphide in the lime mud fed into the kiln. The strength of this source depends on the degree of lime mud washing and its state of oxidation. This source is best controlled by the proper sizing and operation of the lime mud filter.

The TRS emissions from the combustion zone are minimized at excess oxygen levels of 4% by volume or greater. Sufficient retention time must be provided at temperatures above 760°C (1400°F) to oxidize the reduced sulphur compounds. Other combustion variables are the temperature profile, the mud retention time, kiln diameter, gas velocities at different locations in the kiln, and the use of oxygen enrichment. Shorter lime kilns tend to have lower TRS emissions than longer lime kilns. Molecular oxygen can be added to the combustion air of a lime kiln and helps control H_2S generation from the lime mud in the combustion zone. The oxygen must be added together with the primary air to the firing zone at the dry end of the lime kiln.

High dry solids concentration in the lime mud, nowadays normally over 80%, good oxidation across the filter, and low free alkali concentration are the key requirements to reduce H_2S formation from Na_2S. This results partly because H_2S emissions from the lime mud occur primarily from Na_2S dissolved in the aqueous portion and not from the solid portion of the lime mud. Above a threshold Na_2S concentration of 0.2% by weight, the generation of H_2S is directly

proportional to the residual Na_2S content of the lime mud. This linear relationship is similar to that for direct contact evaporation.

With a proper lime mud filter design capacity, a small amount of air is drawn through the lime mud cake to oxidize the rest of sodium sulphide left on the surface of lime mud particles to sodium thiosulphate. Sodium thiosulphate does not cause any H_2S evolution. If problems arise, the reason is in many cases poor lime mud quality which has affected the lime mud dry solids and purity. The presence of green liquor dregs with the lime mud to the cold end of the lime kiln can substantially increase the TRS emissions, because these materials are normally contaminated with Na_2S from the green liquor. The situation can usually be solved by improving the green liquor clarification or by replacing a part of the lime with make-up lime. The evolution of Na_2S at low temperatures in oxidizing atmospheres promotes H_2S formation and TRS, while its evolution at higher temperatures promotes SO_2 formation. It is normally reasonable to expect operating levels of 10 ppm_{DV} H_2S at 10% O_2 with a modern lime mud filter.

In wet scrubber applications, the scrubber water can also be a source of both H_2S and organic sulphur compounds emissions. Accordingly, fresh water should be employed as the scrubbing medium to avoid the stripping of odorous gases. If process condensates are used, they should be steam stripped first, or sodium hydroxide should be added to the scrubber water to raise the pH. The scrubber water is recycled to the causticizing system.

If a tighter level of TRS emission control is required, the installation can be equipped with alkali scrubber following the electrostatic precipitator. The measured H_2S concentration in the stack flue gases has been as low as 1 ppm leaving the scrubber. An alternative is adding a last shower of hydrogen peroxide onto the lime mud filter.
TRS emissions may be controlled to some extent by the scrubbers, depending on the scrubbing medium. The use of sodium hydroxide in the scrubber significantly reduces TRS emissions (3 ppm_{DV}). TRS levels of less than 0.003 kg/t pulp have been reported when NaOH is used. Good operating practices, including good lime mud washing and the use of non-contaminated scrubber shower water, should result in TRS emissions of 0.05 kg/t or less or below 10 ppm.

Volatile Organic Compounds

These emissions originate with contaminants in the process condensates that are typically used to wash lime mud and as wet scrubber water makeup. The condensates contain VOC such as methanol, terpenes, ethanol, some of which remain with the mud going to the kiln. These contaminants are stripped off during the passage of the lime mud through the kiln.

By using fresh water instead of stripped process condensate to wash the lime mud and as make-up water to the lime kiln scrubber, the VOC emission from these sources would be virtually eliminated. However, the displaced process condensate has to go somewhere else in the process or to sewer and effluent treatment. Even if the process condensates are sewered, some overall reduction in VOC emission would be expected, since the stripping of VOCs from an aerated lagoon may be 10-25% of the theoretical maximum while for the lime kiln scrubber and lime kiln it would be 70% or more.

Lime kiln VOC emissions are not expected to be a function of the type of fossil fuel burned, whether gas, oil or petroleum coke. Some testing suggests that NCG burning by itself has no discernable influence on the resulting VOC emissions.

A 1993 study of nine kilns gives a range of VOC emissions expressed as carbon of 0 to 360 ppm_{DV}, with an average 46 ppm_{DV}. This is less than a survey conducted almost a decade earlier where the use of evaporator condensates for lime mud washing increased the VOCs from 79 average (range 32-465 ppm_{DV}) when using fresh water to an average of 465 average (range 31-770 ppm_{DV}), all referenced to10% O_2.

B - 4 Mechanical Pulping

B - 4.1 Pulping

B - 4.1.1 Description of process

Mechanical pulp has certain desirable properties which make it useful in many grades of paper requiring high bulk and good opacity. The pulp is composed mainly of cellulose fibre bundles and fragments with some whole individual fibres. Because of the mixed nature of the particles in the pulp, and because the lignin has not been removed, the pulp properties are a small average particle length and a relatively stiff fibre which provides bulk. This bulkiness, plus the fact that mechanical pulp absorbs ink rapidly, and uniformly, enhances paper printability. Compared with chemical pulp it has undesirable properties such as low strength, harsh feel and lack of permanence since it yellows with age.

Mechanical pulping comprises a number of variants depending on whether there is chemical pretreatment of the wood, the type of fibre separation process and pressure of the defiberizing operation. Mechanical pulping relies mainly on mechanical energy to convert wood to pulp. The processes comprise stone groundwood, refiner mechanical (RMP), thermomechanical (TMP), chemi-mechanical, and chemi-thermomechanical (CTMP).

The most common process is thermomechanical pulp (TMP), where the chips are first usually steamed under pressure for several minutes at 20-40 psi prior to refining. When introduced in the 1970s, the mechanical refiners operated at atmospheric pressure. Today, refining is carried out under pressure to allow recovery of heat in the form of steam which can be used for paper drying. In the mid-1970s, chemi-mechanical, and chemi-thermomechanical (CTMP) were introduced. These processes reduce power consumption at the refiners as a result of adding chemicals. For CTMP the chemical is usually sodium sulphite added at rates of 1-4% Na_2SO_3, which reduces yields from the 95% area to approximately 90%.

For all mechanical pulps the specific energy requirements for the defiberizing is an important process parameter not only as it related to the pulp characteristics, but particularly because of the very large amount of power required to be supplied outside the pulping process relative to chemical pulp.

Mechanical pulping is receiving on-going attention to reduce energy consumption by a broad range of research and development activities in the following areas of:

- Control improvement of consistency, feed rate and plate gap
- Refiner plate design
- Increased throughput rates
- Changed time-temperature profile through the refining process
- Chemical pretreatment of the chips

B - 4.1.2 Air emission sources and control strategies

In all mechanical pulping processes, VOC and HAPs are emitted from the grinders or refiners, and lesser amounts from chip washing and other chest vents. The most detailed data was published in 1997 and shows volatile and semi-volatile HAPs of 0.19 kg/BDt for pressurised groundwood, 0.09 kg/BDt for TMP and 0.035 kg/BDt for stone groundwood with methanol being 23-91% and acetaldehyde 7-32% of the total HAP emission. VOC ranged from 0.032-2.9 kg as C/BDt and consisted mostly of α and β-pinene.[72] VOC emissions include a wide range of compounds, but are very wood species dependent.

In TMP and CTMP processes, part of the steam generated by the refiners is used to pre-steam chips. At about two-thirds of the TMP and CTMP mills in Canada, which include the older ones installed in the 1970s, most of the remaining steam is vented to atmosphere, taking along with it the VOC and HAP. The remaining one third of the mills, including most of the newer ones have a heat recovery system which recover the heat in the steam for use in water or space heating or as clean steam for a paper machine. This results in the condensation of part of the VOC, and hence serves a secondary purpose as an air emission control measure.

Part of the condensate is used for chip washing, but eventually all of it ends up in the sewer system and the effluent treatment plant. With an aerated basin, a small proportion of the VOCs would be stripped by the aeration process and become an area emission source. The balance would be consumed by microbial activity in the aeration basin and be emitted as CO_2 and SO_2, the latter from the small amount of sulphur in the wood and pulping chemical addition if used. No TRS would be expected to be emitted unless generated in anaerobic sections of the aeration basin.

IN THE FUTURE, IT IS EXPECTED THAT CHANGES IN CYCLONE TECHNOLOGY WILL RESULT IN HIGHER CONSISTENCY PULP AND LESS VOLATILES ENTERING THE LATENCY CHEST, WITH THE RESULT THAT MORE OF THE VOLATILES WILL BE CAPTURED IN THE HEAT RECOVERY SYSTEM AND LESS WILL ENTER THE MILL PROCESS WATER SYSTEM. TO MAINTAIN LATENCY CHEST TEMPERATURE, CLEAN STEAM OR CLEAN HOT WATER WILL HAVE TO BE USED.

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[72] National Council of the Paper Industry for Air and Stream Improvement (NCASI), *Volatile organic compound emissions from non-chemical pulp and paper mill sources, Part III – Mechanical pulping*. Technical Bulletin No. 738. July 1997.

ANOTHER SOURCE OF VOC EMISSIONS IS FROM CHIP WASHING. COMPARED WITH EARLY DESIGNS, WHICH USED DIRTY STEAM FOR HEATING, LESS CONTAMINATED WATER WILL BE USED AND VOC EMISSIONS CAN BE EXPECTED TO BE REDUCED.

IN SOME NEWER MILLS HAVE INSTALLED TURPENTINE STRIPPERS TO TREAT PROCESS WATERS WITH LOW CONCENTRATIONS OF TURPENTINE WHERE DECANTATION IS LESS EFFECTIVE FOR SEPARATION. ONE MILL THAT HAS ADOPTED THIS APPROACH IS PULPING A SPECIES OF CHIPS HIGH IN PINENES AND TURPENES AND WAS LOCATED IN A REGION WITH POOR AIR QUALITY.[73] STRIPPER OFF GASES CAN THEN BE BURNED IN A BOILER OR INCINERATOR.

The size of production lines has grown dramatically over the last two decades, though specific power consumption of the refiners themselves has typically only slightly decreased. There have been significant decreases in power consumption of the balance of the TMP plant, so that overall, TMP power has decreased by perhaps 8% since the 1970s. However, it is not the size of production lines that affect VOC emissions per tonne, but more subtle changes in the process, particularly the method of heat recovery and temperature of the process vents to atmosphere which have led to significantly reduced unit emissions.

One mechanical pulp mill at Meadow Lake, SK, uses a closed cycle CTMP process. At the time of its start-up in 1992, it was the first mill of its kind in the world to use evaporation technology to completely eliminate the discharge of liquid effluent from mechanical pulping process. The rationale at this mill for stripping the condensates was to make them more amenable for treatment so as to be clean enough to recycle back to the pulp mill.

B - 4.2 Bleaching

B - 4.2.1 Description of process

The increased demand for higher brightness mechanical pulps for use in printing papers, tissue paper, and paper towelling has led to the development of efficient bleaching processes.

The methods of bleaching mechanical pulps differ fundamentally from those of bleaching chemical pulps, since bleaching to effect lignin removal would result in a drastic yield loss and also would be far too expensive. For this reason, chemicals which alter the coloured impurities and leave the lignin and cellulosic material unchanged are employed, and to differentiate are called brightening processes.

The most commonly used brightening agents are sodium hydrosulphite, which is used extensively on the West Coast to overcome the darker colour of Western groundwoods in the competitive field of newsprint production. Hydrosulphite is relatively inexpensive, particularly when only a few points brightness increase are required. It can be introduced at low capital cost and can be used intermittently to recover the brightness of off-grade pulp if that is required.

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[73] Sueiro, L., Gill, J., *Control of VOC emissions from a TMP plant*, International Environmental Conference, 1995

Hydrosulphites are powerful reducing agents and are capable of achieving net brightness increases of 4-7 points under optimum conditions at the reel.

Peroxide is by far the most effective bleaching agent for most groundwoods and is used whenever high brightness is required. Peroxide is more expensive than hydrosulphite. Either hydrogen or sodium peroxide or both may be used sequentially and in conjunction with other chemicals.

As chlorine-based compounds such as hypochlorite are not used (except very occasionally in semi-chemical pulping), no chlorinated organics would be generated nor be present in air or other emissions.

B - 4.2.2 Air emission sources and control strategies

The origins of bleaching emissions are essentially the same for mechanical pulps as for kraft pulps, but since the bleaching temperatures can be lower, less emissions result. Because of the nature of the chemicals used in mechanical pulp bleaching, no scrubbers are used, unless chlorine-based compounds are adopted.

B - 5 Paper Machines and Pulp Dryers

B - 5.1 Description of process

The paper machine converts the pulp suspension into paper. All paper machines consist of a wet-end or forming section, a press section, and a dryer section. The most common wet end machines in use are the Fourdrinier, the twin wire former, and the cylinder machine.

The Fourdrinier paper machine is the most common device used today and has been successfully adapted to make a wide range of papers, light weight boards and as a preliminary step for pulp drying. During the 1970s twin wire formers which improve paper quality and sometimes production capacity became increasingly popular and are now widely used. Cylinder machines are chiefly used to produce heavy papers, paperboard and non-uniform paper.

Press sections use felt blankets to remove further water from the web, as the full width of paper on the machine is called. The dryer uses heated cylinders and or hot air to evaporate the remaining water from the web to the level required in the final product, whether paper or pulp.

A size press may be located after the main dryer section; sizing solutions such as starch can be added to the surface of the web, giving the paper improved printing properties and resistance to liquid penetration. After sizing, a further drying section is required to remove moisture absorbed in sizing. Newsprint is normally not sized. In fine paper production, the size press might be replaced by an on-machine coater, depending on the grade being manufactured. The dried web may then enter a calender stack where it is compressed to give it a smoother surface prior to reeling.

In the past, the coating of paper was usually carried out in an independent operation because the coater ran at much lower speeds than the paper machines. Today, most medium quality coated papers are coated on the paper machine. Off-machine coaters are used particularly where heavy coating weights are needed or where other conditions exist which do not permit application on the paper machine without slowing it down.

B - 5.2 Air emission sources

There are no environmentally significant atmospheric emissions from this department. By far the most noticeable emission for the paper machine department is the vent from the dryer. This consists of water, vapour, and air but virtually no fibre.

The emissions resulting from the use of solvents as felt cleaners and wire washers depend largely on the type of solvent used. The cleaning solvents may contain volatile components such as trichloroethylene, trimethyl benzene, glycol ethers, or a variety of non-volatile, non-VOC containing proprietary chemicals.

Data published in 1997 in the US provide the most detailed measurement data of volatile HAPs and VOC air emissions taken from 13 paper machines at 11 different mills. These machines used mechanical pulps, recycled fibre, chemical pulp, to produce products that included fine paper, tissue, towel, paperboard, linerboard, backing paper and newsprint. Emissions for VOC ranged from 0.05-0.6 kg as C/BDt[74].

B - 6 Power Boilers, Combustion Turbines, Effluent Treatment and Other Sources

B - 6.1 Power Boilers – Wood Waste and Fossil Fuel Fired

B - 6.1.1 Description of process

The steam plant with its one or more power boilers, and other sources of steam such as any recovery boilers or TMP reboilers, generate the steam to meet all the requirements of the mill. Power boilers may be fossil fuel fired only or combination-fired with fossil and wood fuel. Wood fuel often includes bark and wood waste, commonly called hog fuel. Dewatered effluent treatment sludges can be added to this fuel stream, which are burned for disposal reasons rather than fuel value.

Kraft pulp mills will generally include one or more large wood-fired field erected power boilers to burn the bark and wood waste associated with chip manufacture. Such a mill may include other gas or oil fired boilers as well. Coal fired boilers are infrequently used in Canada. Power boilers in small paper or recycle mills will generally be of the gas fired package type. In older integrated pulp and paper mills, the boilers at a mill may include a variety of types and ages: large wood-fired units;

74 National Council of the Paper Industry for Air and Stream Improvement (NCASI), Volatile Organic Compound Emissions From Non-Chemical Pulp And Paper Mill Sources, Part V – Paper Machines. Technical Bulletin No. 740. July 1997

large field erected oil, gas or coal fired boilers; and package type boilers. New mills are built with normally only one power boiler to reduce manning and maintenance.

Package type boilers are manufactured on a skid and thus limited to smaller sizes of up to about 150 GJ/h. As they are generally a fire-tube design this limits practical maximum pressures to the 1,400-2,100 kPa (200-300 psig) range.

Field erected boilers use water wall construction and are designed for larger steam generation rates and steam pressures than are possible with packaged units. The capacity of field erected units covers the range from 100 to about 950 GJ/h in fuel heat input or from 35 t/h up to about 300 t/h steam. Field erected boilers are generally more conservatively designed in terms of heat release per unit furnace volume, which has an impact on air emissions generated. As they are commonly found in mills and responsible for most of the emissions from boilers of all types because of their large size, and typically fire wood residues and bark, this report only deals with wood-fired, field erected units.

Hog fuel consisting of bark, chip fines and debris from the woodroom and log yard has generally passed through a size reduction process, or hog for easier handling. At some mills, wood residues from sawmill operations are included and broadens the range of material further, which may include very dry, fine sander dust, planer shavings, saw dust, coarsely sized or chipped slabs, cutoffs, veneer clippings and yard waste. To this fuel stream is added dewatered effluent treatment sludges which are burned for disposal reasons rather than fuel value. Burning sludge though avoiding landfill disposal is typically difficult because of the high water or high inert material content, both of which impact negatively on air emissions.

Despite the wide variety of forms, physical properties, and origins in the process of wood based and sludge fuels, the carbon and hydrogen content varies little on a dry, ash free basis. Higher heating values, reflecting the carbon and hydrogen content, is therefore closely grouped in the 19,500-21,500 kJ/kg (8,400-9,200 Btu/lb) range, dry basis.

The amount of steam generated by the power boilers per air dry metric tonne of product varies according to the type of manufacturing process, the energy efficiency of the mill, the other sources of steam and the types of products the mill manufactures and so is not a good parameter to use for comparison. Accordingly, power boiler emissions are best presented per unit heat input (ng/J), rather than per mill production (ADt).

Types of Furnaces

Wood fuel fired boilers use one of several methods of combustion:

- Cell burning – Fuel is fed onto a thick bed or conical pile within a refractory lined furnace or multiple cells, and air is admitted around the furnace/cell walls or through grate blocks. The Dutch oven boilers are typical of cell burning designs and were standard technology for wood-fired boilers until the early 1950s. The high fuel inventory results in poor control of steam generation. Ash removal is normally manual, requiring an interruption of wood firing.

The key advantage of cell burning is the capability to burn wood fuel containing up to 65% moisture content wet basis.

- Grate burning – Fuel is spread relatively thinly over the grate which may be of the horizontal pinhole, inclined/sloping, travelling, reciprocating or vibrating type. Preheated undergrate air passes upwards through grate and bed of fuel.
    - The rugged pin-hole grate has cast iron grate blocks attached to the water tube floor of the furnace and is used in conjunction with a spreader stoker which projects the fuel across the furnace to cover the grate. Removal of the ash is performed manually, and requires firing of oil or gas during ash removal.
    - The sloping grate uses a gravity mass feed system to deliver the fuel to the upper side of the grate. The slope of the grate is designed to allow slow movement of the fuel down the grate through zones of drying, devolatilization, combustion and burnout before reaching the ash discharge section. The absence of airborne delivery of fuel to the grate reduces ignition of the drier, finer wood fuel particles and their carry over along with fine ash from the furnace.
    - The traveling grate has been very widely used for many decades for medium and large capacity wood fuel fired boilers. Cooling of the grate is critical and is only achieved by the undergrate air, which should not exceed about 260°C to prevent grate damage. This limitation in temperature of undergrate air prevents successfully firing higher moisture materials such as sludge.
    - Reciprocating and vibrating grates are air- or water-cooled, which increases the maximum undergrate air temperature that can be used and allows high moisture fuel, in the 60% wet basis range, to be fired. Mounted on a slope, ash is delivered automatically to an ash pit at the low end of the grate. A popular type in North America, because of its simplicity, ruggedness and ability to accept very hot undergrate combustion air is the Detroit Hydrograte. A European example is the Kablitz grate.
- Suspension burning – This firing method is only suitable for very dry - typically below 15% moisture content wet basis - finely divided fuel which burns in flight once inside the furnace. Suspension fired pulverized wood fuel has a fast response, much like oil or gas, to changes in boiler load. Suspension firing is uncommon outside the sawmilling industry because of the absence of very dry fuel and since the complexity and cost of drying and pulverizing wood waste because it is hard to justify.
- Fluidized bed burning – Fuel is introduced into a bed of hot sand. Combustion air fluidizes the bed and creates conditions for complete gasification and combustion of the fuel. Fluidized bed combustion has been successfully applied to a range of wood waste and coals for some time and offers a number of advantages which can outweigh its generally higher cost. The high heat transfer combined with high thermal inertia effect allows higher moisture wood and sludge fuels to maintain self-sustained combustion without the use of fossil fuels.

Fluidized bed combustion temperatures are typically 700-900°C. This is much lower than the minimum temperature required for good grate burning and results in lower NO_x emissions compared with the other methods of burning wood fuels. For non-integrated mills which generally lack a bark burning power boiler, fluidized bed technology would be the choice for a boiler

dedicated to sludge burning. In Europe fluidized bed technology has superseded grate-type fired boilers.

Of the two main types, bubbling bed units tend to be used for the smaller scale applications with fuels of lower heat content such as sludge and wet wood waste fuels. Circulating fluidized bed technology is used on larger units and high heat content fuels such as coal and large wood waste units.

Improving Combustion

Whatever the type of furnace employed, there are a number of other important factors that impinge on the performance, operating convenience, efficient use of fuel, and the effects on emission formation. The wood/sludge fuel characteristics, boiler load, combustion technique, furnace geometry, amount of refractory, overfire air design are all important in determining the need for supplementary fuel firing, and the air emissions carried out of the furnace by the combustion gases.

Moisture has a profound effect on the combustion process, primarily because of its high specific and latent heat of vaporization which directly removes heat from within the combustion process. Small increases in moisture produce large decreases in combustion temperature. In practical terms, the limit is reached in the mid-60% range for wood fuel even for the furnace designs best adapted to wet fuel firing. The result of too low a flame temperature is low combustion effectiveness, which is fuel wastage through excessive unburned carbon losses (also translating into a much greater volume of ash for disposal), and very much higher emissions for most parameters.

To some extent hotter overfire air, refractory in place of water cooled furnace walls and some co-firing of fossil fuels will compensate for inadequate dryness in the fuel. Though the use of fossil fuels for sustaining combustion is widespread in boilers of older design, it has a significant operating cost penalty for even small percentages of moisture above the limit for autogenous combustion.

Modern combustion air systems concentrate an intense, controlled fire immediately over the fuel bed by more effectively promoting furnace gas mixing which further reduces emissions from the furnace. The heat concentration over the grate is sometimes promoted by providing arches over the grate in the furnace walls and constructing portions of the lower furnace walls of refractory to re-radiate the heat back into the fuel bed.

The overfire air systems on older boilers leave much to be desired. Modern units use large diameter jets (60-150 mm) which are located so as to penetrate fully across the furnace. This breaks up the flue gas leaving the grate area which has a tendency to channel up the centre of the furnace.

B - 6.1.2 Air emission sources and control strategies

The power boiler can be in single or multiple units of different types and capacities depending on the nature of the mill. No rule-of-thumb exists that directly links power boiler emissions to mill production. Even in a single product facility, the amount of steam from the power boilers per ADt

of product varies according to the energy efficiency of the mill, whether power is self-generated or the presence of an associated paper mill. Therefore, it is common industrial practice to present power boiler emissions on a heat input basis (ng/J, g/GJ).

The emissions from these units will reflect the age, technology of the boiler and its emission control equipment and the fuels fired.

Oil or gas are commonly fired in combination with wood and sludge fuel, and in some cases, non condensable gases. The approach used in estimating flue gas and air emission properties considers the combustion processes as being carried out separately. Aggregate properties are then obtained by summing the individual contributions.

Carbon Monoxide

Carbon monoxide concentrations are usually quite variable. Conditions of high excess air leading to combustion zone cooling, low excess air, high fuel moisture and reduced load all tend to increase flue gas CO concentration and reduce combustion efficiency.

Based on extensive testing emission data vary widely: median values for Dutch ovens, spreader stoker/grate type and fluid bed furnaces are 315, 645 and 65 ng/J (700, 1500 and 150 ppm_{DV}) respectively, with very wide ranges for each.

Carbon monoxide emissions are minimized by good control of a homogeneous fuel feed rate, maintenance of combustion temperature, adequate excess air and good furnace gas mixing. The control approach is uniformly by in-process means as opposed to add-on controls. Control is achieved therefore through good boiler design, good combustion control by means of continuous measurement of CO and O_2, proper fuel preparation and careful operation. Modern overfire air systems enhance furnace gas mixing through control of windbox pressure, port open areas and the provision of optimally located large air ports, and can often be retrofitted to existing boilers. Many older furnaces lacking furnace residence time or height will not be able to complete the burn out of CO to the same degree.

Nitrogen Oxides

Due to the lower combustion temperatures and low fuel nitrogen content, NO_x emissions from wood and sludge firing are relatively low compared with those originating from fossil fuels burned in standard as opposed to low NO_x burners. In addition, a limited form of staged combustion is already inherent in the manner in which fuel and air are normally introduced in a grate type hog fired boiler. Support fuel firing is often the origin of a significant proportion of the total NO_x emitted in many combination hog and fossil fuel fired boiler operations.

Uncontrolled NO_x emission data is available for the tests performed on 42 spreader stoker boilers, 14 fuel cell (Dutch oven) and 6 fluid bed boilers firing bark and wood residues of 86, 34 and 69 ng/J (118, 47, 95 ppm_{DV}) respectively. NO_x emissions from burning effluent treatment sludges and

recycled paper deinking sludge according to NCASI Technical Bulletin No. 646 may be assumed to be comparable to the emissions from wood residue and bark burning.

NO_x emissions for standard burners average 170 and 470 ng/J (143 and 240 ppm_{DV}) respectively for gas and oil burners respectively. For low NO_x burners with staged combustion or flue gas recirculation, these emission rates can be nearly halved. A recent review of advanced technology low NO_x burners in fossil fuel only fired full size units reports NO_x levels down to about half those values or less for gas and oil firing respectively based on controlled test results.

A number of technologies hold potential for further NO_x reduction of wood-fired boilers. One is more advanced combustion air staging and at least one manufacturer is promoting this with guarantees for new designs. In this way control may be achieved down to the 50 ng/J level, but in practice generally to about twice that level.

Another is flue gas recirculation, which by reducing peak oxygen content and combustion temperatures, reduces NO_x formation. However, the scant information in the literature suggests that the use of flue gas recirculation is not an attractive method of NO_x control for wood fuel fired boilers.

Installations of selective non-catalytic reduction control systems providing 50-80% NO_x reduction on wood-fired power boiler applications exist in the US, but are few in number and limited to installations located in air sheds where air quality does not attain national standards. Selective catalytic reduction presents technical and environmental barriers.

Particulate

About 80-95% of the total ash residue produced by a hog fired grate equipped boiler is in the form of gas borne particulate, called fly ash or furnace carry over. The balance of the total ash residue stays in the furnace and leaves as bottom or grate ash. For fluidized bed combustion furnaces, the carry over is considerably less due to the virtual absence of char due to the high combustion efficiency, though all ash leaves the furnace as carryover. In the case of suspension burning, the carry over is virtually 100%.

Combustion-related factors affect particulate emissions by determining the degree of burnout for the entrained char. These include plan and volumetric heat release rates, which directly affect furnace temperature and residence time. Char burnout is also governed by aerodynamic factors, such as furnace shape, overfire air jet geometry, fuel particle size distribution, char reinjection, the split of under grate to over grate air and combination firing. Char reinjection augments particulate emissions since it decreases average particle size and increases dust loading to the particulate emission control system by 20-100%. Typically 35% of the total particulate from wood waste and bark fired fine is fine particulate.

For wood-fired boilers, the amount of fine particulate leaving the furnace is strongly influenced by the salt content of the hog fuel. At the temperatures in the furnace, the salt fumes and condenses into submicron (< 1 μm) particles as the flue gas cools before release to atmosphere. Studies

indicate that an average of 30% and up to 65% of the particulate matter discharged from the stack is salt when burning wood residues and bark derived from salt water floated logs.

In-process improvements to reduce PM emissions include: supply of drier fuel, elimination of fly ash reinjection, upgrade of the overfire air system of the furnace to improve penetration and gas mixing, modification of the furnace water walls to provide opposed arches and refractory, replacement of the lower furnace with an improved grate or a fluid bed combustor.

The dry-type electrostatic precipitator is currently the preferred external particulate emission control device for its high availability and efficiency. A further advantage is that water is not added to the flue gas as is the case with wet scrubbing, which increases plume opacity and inhibits dispersion. Multiple cyclone type mechanical collectors (multi-cyclones) and most types of wet scrubbers generally represent older technology.

Salt fume in the flue gas resulting from the burning of salt-laden wood, a problem on the West Coast, presents a special problem as the high resistivity results in poor collection by electrostatic precipitators and difficult plate rapping. As the PM exit concentration is decreased, other technologies such as wet precipitators or fabric filters come into their own as alternatives to dry-type electrostatic precipitators. In some permits, the salt particulate component of the emission is omitted in calculation of the emission.

Though fabric filters offer very high PM removal rates, and are cost effective where very low exit emission concentrations are required, the risk of downtime in the event of bag failure due to fire, wear or fatigue prevents their wider adoption. Though used primarily in the sawmill and panelboard industry, electrified filter bed shows promise in high removal rates of both salt and other particulate, but only a few are operating on the large boilers typically found in pulp and paper mills burning salt laden wood.

Sulphur Oxides

Only part of the sulphur in the hog and sludge fuel, fossil fuels and NCG is converted into gaseous SO_2, the balance being adsorbed onto the fly ash or converted into sulphates in the combustion process and removed along with the ash.

In the co-firing of oil and bark, about 10% of the sulphur in fossil fuels emerges in the form of SO_2 in the stack gases, the balance being adsorbed onto the fly ash or converted into sulphates and removed along with the ash. This percent increases when NCGs and more sulphur-rich fuels increase total sulphur input. The mechanism of capture is by the action of alkali oxides and carbonates in the bark or wood residue ash, combined with the high surface area of the fly ash.

Add-on wet scrubbers are able to remove in the order of 80-95% of the sulphur oxides and dry scrubbers, about 70-80%. Scrubbers are only relatively common in Scandinavia where there are coordinated national programs to curb acid rain.

Total Reduced Sulphur

TRS contained in kraft pulp mill NCGs may be directed to the power boiler for incineration. The high reactivity of TRS ensures very complete oxidation to SO_2 and CO_2 in combustion provided there is sufficient excess air, temperature and good furnace gas mixing as found in a modern overfire combustion air system.

Volatile Organic Compounds

The origin of the volatile organic compound emissions from wood-fired boilers are the wood and sludge pyrolysis gases that evolve during combustion process which have not been oxidized before leaving the furnace. Though the mechanism of CO and VOC emissions bears some similarities, little correlation in emissions between the two parameters is evident.

If NCG are fired as well as wood and sludge, the total VOC would reflect the VOCs from the wood, the sludge and that from the foul condensates. VOC input into a power boiler in this case would include terpenes, organic sulphides (methyl mercaptan, dimethyl sulphide, and dimethyl disulphide), acetone, ethanol and phenolics.

Uncontrolled non-methane VOC emission data is available for the tests performed on 42 spreader stoker boilers, 14 fuel cell (Dutch oven) and 6 fluid bed boilers firing bark and wood residues. VOC emissions average 77, 36, 2 ppm_{DV} at 7% O_2 for the spreader stoker, fuel cell (Dutch oven) and fluid bed boilers respectively. Other work gives 0.04 and 0.026 kg as C /GJ (211 and 137 ppm_{DV} at 7% O_2) for wood-fired power boilers with <15% and >25% secondary air respectively.

For combination firing of fossil fuels or NCG with hog fuel, it is suggested as before that, in the absence of test data of the impact of each of the various fuel components on the total emissions, the emission factors applicable to each fuel be apportioned to provide an estimate of the total emission. VOC emissions for standard fossil fuel burners average 0.0010, 0.0015, and 0.013 kg C /GJ (5, 8, 66 ppm_{DV} at 7% O_2), for gas, oil and pulverized coal burners respectively. No change is anticipated from the use of new technologies such as low NO_x burners, staged combustion or flue gas recirculation.

For an existing unit, VOC are controlled in the same way as carbon monoxide emissions are minimized, that is, through in-process controls. Operationally, emissions of volatile organic compounds are minimized by ensuring good mixing in the upper furnace volume, and control of furnace temperature and excess air.

There is relatively little that can be done to an existing older boiler to reduce VOC levels to the lower levels of more modern units, without improving combustion by either firing drier fuel or installing a modern overfire combustion air system or both.

A modern overfire combustion air system would normally be part of any bark fired power boiler upgrade, to improve efficiency, and reduce not only VOC and CO but also the char fraction of the particulate, and unoxidized TRS if NCG are being fired.

B - 6.2 Wood Waste Fuel Dryer

B - 6.2.1 Description of process

Wood waste or hog fuel and sludge drying is carried out to enhance the combustion of the material through higher flame temperatures and faster combustion rate. This brings a number of benefits:

- Displacement of some of the fossil fuel fired through the improved thermal efficiency of the boiler, increasing the steam-from-wood;
- reduced unburned carbon and lower excess air requirements, both improving boiler efficiency;
- improved ease of boiler operation and responsiveness to load changes and operation at low boiler load; and
- substantial reduction in air emissions from the boiler such as particulate, CO and VOC, though NO_x may increase.

Despite these advantages there are relatively few wood fuel dryers still in operation in Canada. The installations at BC's coastal mills have needed expensive maintenance to combat corrosion due to the salt in the fuel, and have had difficulty in effectively collecting fine salt fume particulate from flue gases leaving dryers. As a result, most of the dryers have been retired. In most other parts of Canada, the wood waste is relatively dry, which detracts from the primary economic justification of justifying the capital investment in a dryer to lower hog fuel moisture content.

Hog fuel and sludge dryers can be categorized by their source of heat as flue gas dryers or steam dryers. There are three types of flue gas dryers: rotary, cascade and flash. Steam dryers are of the hot air type or shell-and-tube and the latter are inherently more efficient[75].

B - 6.2.2 Air emission sources and control strategies

From an air emission point of view, it is important for flue gas dryers to distinguish between those using a dedicated source of heat from those using boiler flue gases. The former present a new source to characterize and permit; the latter represent the modification of an existing source.

In either case the source will have an air discharge that contains not only products of combustion and emissions of the boiler or dedicated burner and the water evaporated from the hog fuel and sludge, but also any volatilized substances in the wood waste or sludge being dried.

Emission information from waste wood fuel dryers appears to be very fragmentary. The source of the limited in-house information is test result data supplied by equipment vendors. This is equipment and case-specific and deals exclusively with particulate emissions at dryer inlet and outlet. From this information, it appears that a hog fuel dryer acts as a dry scrubber, with particulate reductions of 40-60% commonplace. The addition of a hog fuel dryer by improved combustion conditions and the dry scrubbing effect can dramatically reduce particulate

[75] Bruce DM, S Hulkkonen, "Steam drying: Benefits, technology and applications", *Pulp and Paper Canada*, 99:12, 1998.

emissions. However, processing salt-laden hog fuel may lead to higher particulate through the volatilization of NaCl at the higher combustion temperatures.

Negative effects will be the wetter, cooler and less buoyant plume and increased VOC emissions.

The principal control variable of a dryer is the temperature of the dry air or flue gas used to remove the moisture. Besides the risk of fires, excessive temperature promotes the volatilization of wood components leading to blue haze emissions. Hot air or gas temperatures at the inlet to the dryer are generally controlled below 400°C. Outlet temperatures are near the water vapour dew point to avoid condensation which would be counter-productive.

In the case of the retrofit of a hog fuel dryer to an existing power boiler, the external air emission controls downstream of the dryer will have to be modified to reflect the changed flue gas characteristics and emission levels leaving the dryer.

B - 6.3 Cogeneration and Combustion Turbines

B - 6.3.1 Description of process

Cogeneration is the simultaneous production of power and useful heat, such as steam, hot water, hot air, or hot oil. Power is typically in the form of electrical power, but could be shaft power. Some or all of the power generated is used by the mill, and any excess exported to the utility grid.

In the past by regulation many jurisdictions in North America required that utility companies supply power which they could do in large scale, centrally-located plants. Industrial plants were sometimes permitted to generate and sell surplus electrical power to these utilities, but usually at uneconomic rates. In recent decades, there has been re-assessment of the role of large electric utilities, and the recognition of the importance of the inherently better efficiency of industrial cogeneration. During the 1990s, the combined effects of a political desire to deregulate power markets and the increased difficulty in permitting large central generating power plants, resulted in a major swing to the large, efficient and reliable combustion gas turbines firing low cost natural gas delivered through an expanding distribution network.

Any manufacturing plant requiring both steam and power lends itself to cogeneration. In practical terms there are two common forms of industrial cogeneration:

- Boiler-based systems burn fuel to generate high pressure steam. A backpressure or extraction condensing steam turbine-generator produces electrical power and meets a process steam requirement. Boiler-based cogeneration has long been used in the pulp and paper industry. As the source of air emissions is solely the boiler stack, the reader is referred to the discussion of control measures earlier in this section.

- Systems based on combustion turbines often called gas turbines generate electrical power and use the exhaust heat to generate steam, which meets a process steam requirement either

directly or in combination with a steam turbine (combined cycle). The air emissions and control measures are discussed in this subsection.

Combustion turbine-based systems are still relatively uncommon in pulp and paper, and tend to be owned and operated by independent power producers who deliver power and steam to the mill under long term contract.

The simplest combustion turbine configuration recovers heat from the gas turbine exhaust gases in a heat recovery steam generator (HRSG) to provide steam for process needs. If the HRSG is designed for higher pressure than the process requires, additional power can be generated by expanding the steam in a steam turbine generator before the steam is distributed to the process.

Finally, the power-to-process steam ratio can be further increased by generating steam in addition to that needed by the process, and expanding this additional steam further in a condensing turbine generator, either in a separate machine or in a condensing section of the steam turbine. As heat is rejected in the condenser, the portion of the power that is generated in the condensing section is produced at lower efficiency than that produced in the backpressure turbine.

Aero-derivative gas turbines are modified aircraft engines, with pressure ratios of 15 to 30 leading to high fuel efficiency. They are well-suited for meeting peak demands of short to medium duration, for cogeneration applications below 50 MW, and where the power and steam generated in the exhaust gas matches the process needs. Industrial units are used where much larger power outputs are required, and where generally lower capital and maintenance costs are more important than high efficiency and high power-to-steam ratios.

The plant configuration chosen for a specific pulp and paper mill or other industrial or institutional application will be dictated by the specific relationships between process heat or steam needs and power required.

B - 6.3.2 Air emission sources and control strategies

The ideal fuel for gas turbines is natural gas. Because of its high hydrogen content, combustion of natural gas produces much less carbon dioxide than oil or coal, and virtually no sulphur dioxide or particulate emissions. Gas turbines can also run on distillate (#2 oil) fuel.

Since the 1970s, gas turbine systems have used steam or water injection into the combustor to control NO_x emissions. Since the mid-80s, dry low NO_x combustor designs have been available which provide greater NO_x reduction than either steam or water injection, and have little effect on CO emissions. The dry low NO_x combustion is a form of staged combustion using more air than normal designs in the combustion path to reduce peak temperatures.

For recent designs in the larger sizes (>50MW) NO_x emission guarantees of 25 ppm_{DV} are typically provided for low NO_x burners, though some recent guarantees for very large machines have been as low as 9 ppm_{DV}. With very restrictive jurisdictions such as southern California where BACT is now 5 ppm_{DV} for simple cycle plants and 2.5 ppm_{DV} for combined cycle ones,

NO_x emission control typically requires the use of selective catalytic reduction, though other techniques are being considered such as hydrogen enriched natural gas fuel, and methane reforming as described in the reference.[76] Throughout this subsection, all concentrations are at reference conditions of 15% oxygen content by volume, the standard for combustion turbines.

It is noteworthy that while many pulp and paper mills import power from the grid to meet demand, the mills that self-generate power and may even export surplus to the grid create additional air emissions at the mill site by so doing. However, the power displaced in Alberta is almost entirely coal based and therefore pulp mill cogenerated power derived from biomass such as bark and black liquor has much less carbon associated with it.

Preliminary estimates of air emissions are available from the US EPA AP42 which has been updated a number of times, the last in April 2000.[77]

B - 6.4 Effluent Treatment

B - 6.4.1 Description of process

Mill liquid effluent leaving a mill requires treatment before discharge to the receiving water. Depending on the characteristics of the untreated effluent and regulatory requirements, primary, secondary, and, in exceptional circumstances, tertiary treatment may be required to reduce the impact of the treated effluent to levels acceptable for the specific aquatic environment of the mill setting.

Pretreatment comprises the initial treatment processes designed to remove grit, coarse material and debris, to neutralize acid or alkaline wastes, and to equalize effluent characteristics and flows by mixing the collected effluent streams and directing the occasionally large flows or concentrated streams, which occur during process upsets and are a normal part of pulp mill operations, to spill tanks or basins.

Primary treatment processes are designed to remove suspended solids from the effluent and normally include the dewatering of the recovered settled solids or sludge to facilitate disposal to landfill or combustion. Primary treatment is a prerequisite for most secondary treatment processes. The sludge from this process is combined with secondary sludge, if any, for common disposal.

Secondary treatment processes reduce the biodegradable portion of the dissolved organic constituents of the effluent. This biodegradable portion is expressed in terms of Biological Oxygen Demand (BOD). Biodegradable material discharged to receiving waters consumes dissolved oxygen, and may deplete oxygen to the point of causing death of fish and other aquatic life. Most secondary treatment processes also reduce toxicity to fish. The most common

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[76] Phillips, J.N., Roby, R.J., *Hydrogen Enriched Natural Gas Offers Economic NOx Reduction Alternative*. Power Engineering, May, 2000.

[77] AP-42 summary of changes to sections incorporated into Supplement F for stationary Internal Combustion Sources: http://www.epa.gov/ttn/chief/ap42/index.html

secondary treatment is the aerated stabilization basin. However, aerobic high rate biological effluent treatment processes such as activated sludge are becoming more common and are generally required in newer mills. The organic suspended solids produced as a result of the biological activity is removed from the treated effluent and mixed with the primary sludge and dewatered prior to burning or other disposal.

Tertiary treatment is the final process of effluent treatment embracing a range of processes which are used to remove further contaminants such as colour, odour, taste, and toxicity from effluent. This involves processes which may involve the addition of reagents or passage through media or beds to remove additional dissolved chemicals and organics, dissolved gases and residual suspended solids and biodegradable material. The sludge of spent reagent produced by this process requires appropriate disposal.

B - 6.4.2 Air emission sources and control strategies

Effluent contains VOCs, HAPs, and in the case of kraft mills, TRS as well. Some of the compounds are relatively volatile such as TRS and terpenes and to a lesser extent methanol and phenols. These compounds can be air stripped and released to atmosphere in effluent cooling towers and by secondary biological treatment aeration systems, but also can be emitted from exposed surfaces of primary clarifiers, settling basins, and spill basins, open channels and any exposed surface of effluent. The amounts emitted can be very little to significant and will depend on the relative volatility of the compounds, the effluent temperature and the air to effluent contact ratios.

TRS emissions from effluent treatment systems are typically associated with the discharge of foul condensates or high strength waste water into the sewer system during leaks or tank overflows that exceed the capacity of the departmental spill control, containment and recovery systems. A second source can be from anaerobic activity in the treatment plant resulting in the formation of sulphide material and subsequent sulphur emissions.

All these emissions are the result of dissolved sulphide levels in the effluent forming a vapour pressure of TRS in the air above the liquid surface. The aeration basins of activated sludge treatment systems and secondary clarifiers do not release any significant TRS compounds.

Steam stripping of the contaminated evaporator process and digester condensates (blow tank, turpentine condenser) before reuse and discharge to sewer remains the most common way to reduce TRS air emissions from the effluent treatment system and from areas of the mill where unstripped contaminated or combined condensates are used. Steam stripping of contaminated condensates and disposal of the off gases by incineration is effective for VOC and HAP control in all pulping processes whether kraft, sulphite or mechanical pulping and the mill effluent treatment systems as well.

In mills where sulphide containing streams are introduced directly into the aeration tanks do not see increased TRS emissions in the activated sludge treatment system aeration tanks. In the US EPA Cluster Rule, this "hardpiping" disposal of contaminated condensates is an acceptable alternative to steam stripping to avoid atmospheric discharges and is used in many mills.

Some older mills have very large lagoons for their Aeration Stabilization Basin (ASB) biological treatment systems. These mills may have emission levels in the 45 to 10000g/ADt range according to an older source[78]. Use of deep basins and fine bubble aeration instead of surface aeration would be expected to decrease TRS and VOC release from the effluent treatment system.

In the past, there has been little regulatory focus on emissions from treatment systems because of measurement difficulties, but they have been of concern as such low elevation sources have been shown to be the source of odour complaints.

A recent environmental review of two Uruguayan mills summarizes recent information on this source of air emissions in relation to the expectation of emissions from new mills[79]:

- Measured emission rates for Finnish mills, in which use of steam stripping is universal, as part of IPPC-BAT is reported as from 5 to 27 g/ADt, for both aeration stabilization basin and activated sludge systems
- The primary clarifier will be used for effluent flows containing fibre and solids, but not black liquor or sulphide-containing streams, to avoid TRS emissions discharging to atmosphere.
- Two states in the US are requiring data to be collected on emissions from effluent treatment systems. In North Carolina, this is only required for mills using aeration stabilization basins as an activated sludge system is considered to be adequate odour control. Mills with aeration stabilization basins system are required to undertake engineering and economic studies to upgrade effluent treatment to an activated sludge treatment system, as a prelude to regulatory pressure to do so.

The discharges to atmosphere from a TMP effluent treatment facility would not include TRS. Because of the high concentrations of organic material in the untreated effluent, other air emission parameters such as VOCs may be higher than for a kraft mill of similar production capacity.

In the case of the relatively uncommon anaerobic effluent treatment systems, methane and similar gases will be given off by the treatment process. In some cases these off gases are burned in a power boiler to recover the fuel value of the gases and reduce air emissions.

B - 6.5 Fugitive, Diffuse and Miscellaneous Sources

Minor and miscellaneous process sources of TRS have often been termed fugitive emissions and originate from pump seals, valve stems, and gaskets that are often widely dispersed within the mill and of uncertain emission rate, albeit typically very small to virtually zero. While they have

[78] Esplin, G., "Total reduced sulphur emissions from effluent lagoons," Pulp and Paper Canada, 90 (10), pp. 105-107 (Oct. 1989).

[79] Cumulative Impact Study for two recent Uruguayan pulp mills:
Cumulative Impact Study – Uruguay Pulp Mills, EcoMetrix Incorporated, Sept 2006.
http://www.ifc.org/ifcext/lac.nsf/AttachmentsByTitle/Uruguay_CIS_AnnexC_Oct2006/$FILE/Uruguay_CIS_AnnexC_Oct2006.pdf

contributed some odour, they have not been of sufficient flow, concentration, or flow continuity to justify collecting in one of the NCG systems. Such fugitive emissions are exhausted to the atmosphere via the area ventilation system.

As well, small vents or stacks from the pulp mill or paper machine plants, plant ventilation, emergency vents pulp and paper mill effluent sludge landfills and wood waste disposal piles may be considered diffuse or fugitive emission sources.

Although pulp and paper mill sludge landfills have been in widespread use for decades, there have been no indications that gas migration from these sites has created a significant industry odour problem. Several recent studies have, however, documented the generation of significant quantities of methane gas from pulp and paper mill sludges and therefore a contributor to greenhouse gas emissions. This is particularly true as increasing quantities of secondary sludge are added to primary sludge, and the nutrient content of the combined solids becomes adequate to support the anaerobic activity. Based on estimates from laboratory studies, it appears that the anaerobic digestion of pulp and paper industry sludges may produce digester gases, containing 50-70% methane, at rates of approximately 6.5 to 8.1 ft^3/lb of volatiles destroyed (0.4 to 0.55 m^3/kg). These estimates are in agreement with the experience regarding the anaerobic digestion of municipal sludge.

There are miscellaneous emissions generated in materials handling operations in pulp and paper manufacturing in addition to those described previously including:

- Salt cake unloading
- Burned lime handling
- Power boiler ash and fly ash handling
- Purchased limestone and lime storage and handling
- Dried lime mud storage and handling and
- Miscellaneous bulk chemical handling and storage for TiO_2, dyes, clays, alum, sulphur, soda ash, talc, etc.

These sources are less important emissions in terms of duration and mass emission rate and contaminant. The degree to which these operations emit will be equipment-specific and depend largely on operating practices. In a number of cases where the materials have a high potential for dusting, such as talc, vendor supplied or recommended transfer equipment will include particulate control equipment such as bag houses or cyclones. There appear to be however, no formal guidelines.

Unpaved roads are a major source of fugitive particulate emissions, due both to their prevalence and to their potential for emissions. Emissions from unpaved roads were estimated to account for 47% of the total particulate emissions in the US from open sources in 1976. This figure is 18 times the emissions from all conventional sources. The major factors affecting these emissions include vehicle speed, roadway type and particle size and density, moisture content, vehicle tire contact area, and vehicle weight and size.

The major determinant in the emissions from paved roads appears to be the silt loading on the road surface. This would result from mud and dirt carry-on from adjacent unpaved areas, sanding and salting for ice control, spills, and erosion deposition from adjacent areas.

APPENDIX C -Air Emission Control Measures and their Costs

APPENDIX C - AIR EMISSION CONTROL MEASURES AND THEIR COSTS

C - 1 Background and Assumptions

Advances occur continuously and progressively over time in the production processes and equipment in the manufacture pulp and paper. As well, the maximum size of new single production lines tends to grow. These advances eventually give rise to technological obsolescence within the stock of existing mills in the form of shortcomings in equipment, in the process design and in the layout. The short-comings may take the form of excessive operating and maintenance manpower requirements, marginally economic or uneconomic scales of operation, quality issues, uncompetitive 'cash cost' (operating cost) or unresolved environmental deficiencies. The variance from new mill 'best current practice' whether in terms of US BACT or IPPC-BAT tends to increase with time as new world class mills grow in size and improve through technological advancements.

Possible remedies may range from periodic though relatively minor improvements, through to mill modernisations where major groups of equipment or systems, departments, or whole plants are completely replaced. Such investments can face major constraints in existing mills such as:

- production capacity bottlenecks which are expensive to resolve;
- restricted physical space; or
- suitability of the existing mill to move toward higher value added products.

The measures described in this section and the order of magnitude cost estimates presented do not consider the effect of such major constraints, and are therefore hypothetical and presented for illustration purposes only.

The age of the present stock of mills in Canada varies widely. While a few of them are relatively recent designs using generally up-to-date emission control technology, the majority of the mills are at least several decades old. For instance, in the case of kraft mills only, the age distribution is approximately: 14% < than 20 years old, 23% between 21-30 years, nearly two-thirds are over 30 years old. However, this statement could be easily challenged, since it is misleading to ascribe a single "age" to most mills because typically mills undergo periodic upgrades and modernisations of their processes and equipment, often too a patchwork of improvements across the mill. These changes can make it misleading to give a unique technological age to a mill.

This is true though to a lesser degree for two Alberta kraft pulp mills, as the other two, the Daishowa-Marubeni mill at Peace River and the Alberta-Pacific mill at Boyle are the newest greenfield mills in Canada, having been started up in the late 1980s/early 90s.

C - 2.1 Basis of Cost Estimates

Cost information presented here is an update of the cost information contained in a previous Simons (now AMEC) report which was based on literature sources and in-house cost

information.[80] The cost estimates have been adjusted for inflation so that it is anticipated that they would be illustrative of the order of magnitude total installed cost and operating costs in mid-2007.

The capital and operating cost estimates are presented in terms of capital (total installed direct + indirect costs), annualized total cost (operating costs + a capital recovery charge), cost per tonne of mill production, and cost per tonne of pollutant removed. The information provides a preliminary estimate of the possible range of these costs for the more common emission control measures. The spread of these costs reflect a range of situations such as between:

- existing and greenfield mills
- mills of small and large production capacity
- high and low cost installations

In the case of existing mills, small and large were taken to be 300 and 800 ADt/d, while for new greenfield mills small and large were taken to be 800 and 1500 ADt/d respectively.

Further broadening of the range of costs arises when expressing the control measure costs on a dollar per tonne of pollutant removed because of the range of possible pollutant removal rates which tend to be mill specific and data show could vary several-fold.

In any formal analysis of control alternatives for a given mill, estimates based on basic engineering of the facility or system are required. But prior to this are key pre-feasibility and feasibility studies that review alternative approaches and include rough estimates of cost. This process generally results in one alternative being recommended, but two in some cases where alternative costs are close. The process of undertaking basic engineering and preparing detailed cost estimates comprises the preparation of technical specifications; comparisons of equipment vendor bids particularly technical specifications, performance guarantees and pricing; estimates of civil/structural, mechanical, electrical and process control systems; and indirect costs to cover construction management, engineering, owners site costs and contractors overhead. Accordingly, there may be significant differences between the costs presented here and the estimated costs for a particular installation developed during basic or definition engineering.

Estimates of operating costs provide an order of magnitude of the allowances that should be made for labour, maintenance, energy and capital recovery costs for the emission control measure. The costs of electricity have been assumed at $50/MWh.

Steam cost of $7.50/t assumes that the incremental fuel used is 70% wood waste and 30% natural gas at $7.00/GJ. Actual costs for a mill may vary by a wide margin. In general, steam consumption used by emission control equipment is not significant. Two exceptions stand out: one is the retrofitting of a wet scrubbing where hot water generation displaces steam used to heat warm water and reduces the steam load on a boiler. The second is a low odour conversion,

80 Environment Canada, *A Summary Report on Pulp and Paper Industry Air Emissions*, H.A. Simons Ltd. (now AMEC), May 1995

where the value of steam is an important contributor to the justification of such projects, and, being significant, must be priced accurately.

An allowance of 4% of capital is made for taxes, insurance and administration; 4.6% of capital for maintenance, maintenance overhead, and spare parts. A capital recovery factor of 16% is assumed. This covers interest payments and payback of the initial investment over the assumed 20 year life of the project. It is noted that the inverse of the annual capital recovery charge is the simple payback, which in this case is 6.3 years. This payback is entirely inadequate in the industry today because of its economically depressed state. However, this is consistent with the US EPA methodology on capital cost recovery relating to emission control facilities.[81]

When the emission rate of more than one contaminant is affected by a control measure, this report attributes the total annualized cost for the control measure entirely to each pollutant in turn. Thus, for example, though pollutant removal costs may be presented for NO_x, TRS, and VOC for the same control measure, the pollutant removal costs themselves are not additive.

The following sections are organized by mill area and consider the most common control measures for the conventional emission parameters. The measures selected are a mix of those applicable to existing older mills and those applicable to newer mill designs. No attempt has been made to determine if the measures are relevant to the Alberta kraft pulp mills in their present configuration, though some measures are clearly not applicable such as Concentrated NCG systems since all the mills have them, nor is low odour conversion as all recovery boilers are low odour type (no direct contact evaporator).

C - 2 Wood Handling and Storage

Particulate emissions from this source originate from chip handling and mobile equipment movements. Besides the use of belt instead of pneumatic conveyors which diminish dust generation, and good engineering practice in design, such as enclosing conveyor galleries, no control is currently practical, given the large area involved for many of these sources.

VOC emission data suggest the source is significant, but emission factors have not been developed. Means for VOC capture and treatment presents practical problems and are probably not cost effective.

C - 3 Chemical Pulping

Long established in the kraft industry is the practice of collecting the strongest TRS sources and burning them in the lime kiln. As the lime kiln is not available all the time, a power boiler is often used for backup. Since the late 1980s, all new mill designs include collection of the weaker sources in a DNCG system.

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[81] USEPA, Office of Air Quality Planning and Standards, *OAQPS Control Cost Manual - Forth Edition*, EPA 450/3-90-006. January 1990.

The NCG collection and disposal methods are summarized in Table C - 1.

Table C - 1: Kraft Fibreline and Miscellaneous Emission Control Measures

Concentrated NCG System TRS and VOC Reduction	Dilute NCG System TRS and VOC Reduction
Description: Collection of concentrated (low vol / high conc.) non-condensable gas, followed by white liquor scrubbing, and disposal in kiln, power boiler, or dedicated incinerator. Sources collected[a]: • digester flash and turpentine condenser • evaporator hot well	Collection of weak (high vol./low conc.) non-condensable gas and disposal in one of the boilers. Sources collected include: • chip bin and feeder vent • brown stock washer hoods, filtrate tanks • most tanks in the screening, brown stock and evaporator areas
Applicability and Prevalence: Canada: Universal in new mills, believed retrofitted to about 75% of existing mills[b] USA: 92% of mills[c] Nordic: 97% of mills[d]	Canada: Found in many newer and modernized mills, or about 10 - 15% of Canadian mills. USA: 6-9% of mills, depending on source[c] Nordic: 18-41% of mills, depending on source[d]
Benefits: Reduction of the strongest TRS odour sources, as well as high proportion of TAC/HAP and VOC. The sulphur reduction from stripper overheads is considered under Effluent Treatment section, with steam stripping as a control measure.	Further reduction of odour as well as TAC/HAP and VOC.
Potential Emission Reduction Assumed TRS: 1.2-2.2 kg/ADt as H_2S VOC: 3-5 kg/ADt as CH_4	TRS: 0.08-0.2 kg/ADt as H_2S VOC: 0.4-0.9 kg/ADt as CH_4
Constraints and Considerations Operating problems on kilns. As TRS in the power boiler and kiln is converted to SO_2, high SO_2 may cause boiler corrosion or require an SO_2 scrubber.	High cost of routing large diameter collection pipes in existing facilities.

Notes:
a - The capital and operating cost of the condensate stripper and its TRS contribution affects air emissions from the effluent treatment system, and is accordingly presented in that subsection.
b - From the 1992 survey data Table 4.14, "Estimates of NO_X, and VOC Emissions for Canadian Pulp and Paper Mills", Stanley Industrial Consultants, May, 1993.
c - estimated from data presented on page 3-4 of "Pulp, Paper, and Paperboard Industry Background Information for Proposed Air Emission Standards, Manufacturing Processes at Kraft, Sulphite Soda and Semi-chemical Mills"; USEPA-453/R-93-050a; October 1993 (Cluster Rules background information).
d - p58, SEPA, Swedish Environmental Protection Agency, Reference Report 4008, "Reduction of Atmospheric Emissions From Pulp Industry", 1992.

The order of magnitude estimates of cost corresponding to these measures are presented in Table C - 2. The cost of operating the CNCG system benefits from the fuel value of the material, particularly methanol, recovered and burned. However, since most of the methanol is obtained from the stripper, this credit is applied to the steam stripping of condensates presented in Table C - 13 and C - 14, Effluent Treatment.

Table C - 2: Kraft Fibreline and Miscellaneous Source Emission Control Costs[a]

Concentrated NCG System		Dilute NCG System	
Existing older mill TRS reduction	**New greenfield mill TRS reduction**	**Existing older mill TRS reduction**	**New greenfield mill TRS reduction**
Capital Costs, in M$			
2.3-5	2.5-6	4.5-11	4.7-13
Annualized Capital Cost in k$/a			
370-800	400-1000	700-1800	700-2100
Operating Cost in k$/a			
90-200	190-400	420-1000	450-1100
Annualized total cost of Control Measure in k$/a			
460-1000	590-1400	1100-2800	1200-3200
Annualized total cost of Control Measure, $/ADt production			
2.15-4.40	1.70-3.30	5.70-9.90	3.50-8.70
Pollutant Removal Costs,			
$/t TRS as H_2S	$/t TRS as H_2S	$/t TRS as H_2S	$/t TRS as H_2S
980-3700	780-2800	28,000-124,000	18,000-110,000
$/t VOC as CH_4	$/t VOC as CH_4	$/t VOC as CH_4	$/t VOC as CH_4
430-1500	340-1100	6300-25,000	3900-22,000

Notes: a - Order of Magnitude costs for equipment described in Table D - 1. See section Basis of Cost Estimates for details.

A stand alone incinerator would be expected to have capital costs at the higher end of the range would include a white liquor scrubber and an SO_2 scrubber. The incinerator burns fossil fuel. The heat released is normally not recovered. Reasons for a stand alone incinerator are the lack of sufficient NCG burning capacity, unfavourable impact of NCG burning on operations and maintenance of boilers and kilns, unacceptable availability of kilns and boilers or the need to scrub SO_2 which is more economically achieved in stand alone incinerators. About 6 stand alone incinerators were operating in Canada in the mid-90s.

In the past, a standby flare has occasionally been provided in the US and Europe. Though low in capital cost, perhaps only 50% of the TRS is converted to SO_2, and this ineffectiveness militates against its more widespread adoption. Now, some of the newest designs fire both CNCG and DNDG in the recovery boiler with backup for both systems in a single stand-alone incinerator with an SO_2 scrubber. The backup incineration of DNCG stand-alone incinerators has been made more practical in these new mills by the reduced volumes handled, mainly due to the use of totally enclosed wash presses instead of vacuum filters and hoods.

For additional sulphur emission reduction, caustic scrubbing of the combustion device is sometimes considered. It is believed that the only SO_2 scrubber relating to NCG disposal in Canada is installed on a stand alone incinerator in Western Canada. Wet scrubber installations are most often found in the case where primary disposal is by stand alone incinerator. The large volumes involved when scrubbing power boiler flue gas present an economic barrier to alkaline scrubbing when NCG is incinerated there. In the case of lime kilns, some capture of SO_2 occurs in the kiln and emission control device whether a scrubber or an electrostatic precipitator. Again, the large volume of flue gases from lime kilns make scrubber addition expensive in terms of SO_2 removed, relative to stand-alone incinerators.

In existing US and Nordic mills, surveys in the mid-1990s show that most of the concentrated NCG collected is burned in the lime kiln (≈ 58%). In the US, incineration in the power boiler (≈ 19%) is next most common practice, then stand alone incinerator (≈ 8-11%), with disposal in the recovery boiler much less prevalent (≈ 4%). In the Nordic countries, the stand alone incinerator

approach is much more common (≈ 43%), where three quarters of them have SO_2 scrubbers reflecting the importance of the acid rain issue there.

C - 4 Mechanical Pulping

Since best available technology includes a heat recovery system, this results in the condensation of the majority of the VOC generated in the refining process, and provides a degree of air emission control. The technical potential and practical limits of retrofitting heat recovery as an air emission control measure has not been evaluated.

C - 5 Bleaching

Only vents from stages where chlorine or chlorine dioxide is added are normally collected and scrubbed. This practice is almost universal due to the requirements for workplace safety, and is generally subject to permitting as well. Since the pulp and wash water are so clean at this point in the process, relatively small emissions resulting from the alkaline stages are not treated.

C - 6 Chemical Recovery – Kraft

C - 6.1 Kraft Recovery Boiler

Measures available today to reduce a variety of emissions from recovery boilers for many existing mills are summarized in Table C - 3. Although none of the Alberta kraft mills have direct contact evaporators and use the more modern low odour designs, low odour conversion is retained for reference in developing costs as this is an option available to a number of older recovery boilers in Canada.

Table C - 3: Recovery Boiler TRS and PM Emission Control Measures

Air System Upgrade NO_x reduction	Low Odour Conversion and High Solids Firing TRS Reduction	Electrostatic Precipitator Upgrade PM Reduction
Description: Installation of a three or four level air system, large ports, variable area dampers, automatic port rodding, stationary firing, bed cameras, and upgraded combustion controls.	Removal of DCE, addition of a black liquor concentrator to increase DS to 72% or more, recover more heat and upgrade the electrostatic precipitator to handle higher flow volume and meet current PM limit.	Existing Recoveries: Upgrade of existing ESP (rigid electrodes, controls), and addition of new two chamber ESP for 1/3 of the flow. New Recoveries: Increased removal efficiency by increasing collection area.
Applicability and Prevalence: Kraft recovery mills built before the early 1980's. In the order of 10-20% kraft recovery boilers in Canada have modern air systems (new or upgrades).	Kraft recovery furnaces with DCE's where location makes the odour problems a public issue. A number of the 25 or so DCE-type kraft recovery boilers in Canada are candidates for low odour conversion.	Existing Recoveries: Kraft recovery boilers built before the mid-1980s, though many have been upgraded. New Recoveries: This expenditure would probably be made in areas where PM is of concern in Canada.
Primary Justification and Benefits: Better furnace mixing and concentrating the heat in the lower furnace which reduces emissions. A small capacity increase is sometimes possible.	Energy efficiency and increased net steam generation of about 10%, and potential to generate more power. Major reduction of TRS, even if the black liquor is oxidized.	Existing Recoveries: Reduction of PM emissions, reduced downtime and possibly maintenance. New Recoveries: Reduced PM emissions
Potential Emission Reduction Assumed NO_x reduction of 0.1-0.2 kg as NO_2 per ADt. VOC reduction of 0.1-0.2 as CH_4 per ADt. CO probably reduced and cases of very poor mixing, possibly some TRS as well.	SO_2 reduction of 1.3-2.3 kg as H_2S /ADt. TRS reduction from 0.15-0.4 with BLOX[a] to 0.05 kg as H_2S /ADt, i.e, down to 3-6 ppm_{DV} @ 8% O_2. VOC reduction from 0.2-0.6 kg as CH_4 /ADt. Reductions in CO, PM and most TAC.	No limit to reduction of PM and PM_{10} by adding collecting area. Existing Recoveries: assumes reduction from 225 to 30 mg/SDm^3 at 8% O_2, about 2.2 kg/ADt. New Recoveries: assumes reduction from 100 to 30 mg/SDm^3 at 8% O_2, about 0.8 kg/ADt.
Constraints and Considerations Uncertain prediction of emission reduction, increased exit gas temperature and potential for fouling of heat exchange surfaces.	High costs, potentially higher if space limited in older mills. Inherent capacity limitations of smaller old boilers may make it impractical. SO_2 will increase without firing at high solids (≈72%). NO_x may increase.	Existing Mills: High costs due to space limitations in some cases. Mill specific studies required to reduce cost uncertainty. New Mills: Need and Cost.

Note: a - BLOX is black liquor oxidation

The order of magnitude estimates of cost corresponding to these measures are presented in Table C - 4. The cost of removal has been attributed to the pollutant for which the technology is most commonly applied.

Table C - 4: Recovery Boiler Emission Control Costs[a]

Air System Upgrade	Low Odour Conversion	Electrostatic Precipitator Upgrade	
Existing older mill NO_x reduction	Existing older mill TRS and VOC reduction	Existing older mill PM reduction	New Greenfield Mill PM reduction
Capital Costs, in M$			
0.6-1.3	15-40	6-12	1.9-4.2
Annualized Capital Cost in k$/a			
100-210	2400-6400	900-1800	300-670
Operating Cost in k$/a			
60-100	1200-3200	380-800	150-320
Annualized total cost of Control Measure in k$/a			
160-330	3600-9600	1300-2600	450-1000
Annualized total cost of Control Measure, $/ADt production			
0.80-1.30	20 - 41	6 -11	1.3 -2.3
Pollutant Removal Costs, $ per tonne			
NO_x as NO_2:	SO_2 as SO_2:	PM	PM
3800-13,000	8800-32,000	3400-17,000	1600-2900
VOC as CH_4	TRS as H_2S:		
4200-13,000	50,000-280,000		
	VOC as CH_4		
	34,000-210,000		

Notes: a - Order of Magnitude costs for equipment described in Table D - 3. See section Basis of Cost Estimates.

The foregoing systems are often found to be the most operationally satisfactory and cost effective. Another control measure that was advantageous in the past is wet scrubbing, particularly when there is a need for hot water in the bleach plant, or for reduced emissions of SO_2, particulate, or TRS. However, modern mills use less water and can meet almost all their hot water needs by recovering secondary heat from the process, rather than flue gases.

Designing for higher solids firing has been the trend in boiler designs of the last two decades, and now 74-78 % is commonplace for new units. Retrofitting for high solids firing from say 65% to 76% dry solids in existing boilers may be considered as a cost effective way of reducing SO_2 emissions. The difficulty is in assessing what the capital cost might be as the solutions may be relatively minor "tweaking" of an oversized evaporator plant at essentially no cost to replacement of the concentrator at $10 M. Accordingly, the high solids firing option is not considered in isolation, but is included with the low odour conversion measure already described.

Selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR) and flue gas recirculation are proven technologies for large industrial and utility boilers. For recovery boilers, in-furnace NO_x control, i.e., selective non-catalytic reduction (SNCR) and flue gas recirculation options are not practical, since they interfere with the chemical recovery process. SCR for this application is believed to be unproven.

C - 6.2 Smelt Dissolving Tank

A control measure for older installations currently using mesh pads and spray is the retrofitting of a dynamic scrubber using uncontaminated weak wash as a scrubbing medium. This measure is presented in Table C - 5.

If process condensates are used in the recausticizing area, these should be of sufficiently high quality to prevent contaminants being brought back by the weak wash and resulting in excessive vent scrubber TRS and VOC emissions. If this is not possible, stripped condensates or clean water should be used on the scrubber.

Table C - 5: Smelt Dissolving Vent Emission Control Measures

Scrubber Upgrade **Existing older mill**
Description: Installation of a dynamic scrubber to replace mesh pads and sprays.
Applicability and Prevalence: Kraft recovery mills built before the early 1970s. Perhaps half of the kraft recovery boilers in Canada have scrubbers.
Primary Justification and Benefits: Reduction of TRS by 60-80%. PM, SO_2, and VOC emission reductions as well.
Potential Emission Reduction Assumed: TRS reduction from the 0.04-0.08 kg as H_2S/ADt with mesh pads to the order of 0.015.
Constraints and Considerations: High retrofit costs and need for detailed study on scrubbing medium.

The cost of upgrading to a dynamic scrubber is presented in Table C - 6.

Table C - 6: Smelt Dissolving Vent Emission Control Costs[a]

	Scrubber Upgrade **Existing older mill**
Capital Costs in M$	1.8-3.8
Annualized Capital Cost in k$/a	230-600
Operating Cost in k$/a	190-370
Annualized total cost of Control Measure in k$/a	470-980
Annualized total cost of Control Measure in $/ADt production	2.4-4
Pollutant Removal Costs, $ per tonne	
TRS as H_2S:	60,000-160,000
PM	2600-13,000

Notes: a - Order of Magnitude costs for equipment described in Table D - 5. See section Basis of Cost Estimates for details.

C - 7 Lime Kiln

The lime mud formed in the recausticizing operation is calcined in the kiln or calciner to regenerate calcium oxide for reuse. Calcination requires high temperatures, up to 1100°C to complete the reaction. The air emissions from the kiln of CO, PM, SO_2, and TRS, are all less than 10% of total mill emissions in a typical older or newer kraft pulp mill, with the exception of NO_x which can be as high as 20% of mill total. In addition, CO_2 emissions originate from both the combustion of fuel and the calcining reaction.

The use of low NO_x burners in lime kilns is not believed to be currently practised because of the need for high calcining temperatures, nor is NO_X otherwise controlled in kilns.

Until the 1980s, particulate emission control was with a wet scrubber. Since then the electrostatic precipitator has been the standard technology for new mills. Though the precipitator option creates less pressure drop and uses less power, the capital cost is higher than the scrubber alternative.

In most retrofit situations, the electrostatic precipitator will be more expensive than a scrubber for the same level of control, even after including for larger lime mud washing and filtering capacity because of water recycled in the case of the scrubber option. However, when two kilns are being retrofitted simultaneously, a single electrostatic precipitator serving both have been found cost effective.

Sulphur dioxide emissions resulting from NCG incineration or heavy fuel oil firing in the kiln are most cost effectively controlled by removing sulphur gases from the NCG upstream of the kiln in a white liquor scrubber. There are examples of alkaline scrubbers operating on kilns for SO_2 removal in the US and Scandinavia.

TRS emissions are minimised by combustion control, ensuring good lime mud washing with clean condensates, and by having a generously sized lime mud filter to oxidize the maximum amount of sodium sulphide entering the cold end of the kiln. The cost of an upgrade to achieve the current TRS emission levels of new kilns, or about 12 ppm_{DV} at 10% O_2, vary from minimal to several million dollars.

The control measure of retrofitting an ESP to an older lime kiln equipped with a wet scrubber is presented in Table C - 7.

Table C - 7: Lime Kiln PM Emission Control Measure

Replacement of a Wet Scrubber with an ESP **Existing older mill**
Description: Installation of a new ESP to replace an existing wet scrubber.
Applicability and Prevalence: Lime kilns built before the early 1980s.
Primary Justification and Benefits: Reduction of PM assumed from present 300mg/SDm^3 range to 30 mg/SDm^3 at 10% O_2. TRS and VOC emission assumed not affected.
Potential Emission Reduction Assumed PM: ≈270mg/SDm^3 at 10 % O_2, about 0.35 kg/ADt.
Constraints and Considerations High retrofit costs for PM control.

The cost of the lime kiln emission control measures is presented in Table C - 8.

Table C - 8: Lime Kiln Emission Control Costs[a]

	Replacement of a Wet Scrubber with an ESP **Existing older mill**
Capital Costs in M$	2.3-7
Annualized Capital Cost in k$/a	370-1000
Operating Cost in k$/a	10-40
Annualized total cost of Control Measure in k$/a	380-1100
Annualized total cost of Control Measure in $/ADt production	2.5-5.5
Pollutant Removal Costs, $ per tonne	PM: 7000-35,000

Note: a - Order of Magnitude costs for the equipment upgrades described in Table D - 7. See section Basis of Cost Estimates for details.

C - 8 Power Boilers

The emission control measures presented are for large, field erected combination wood and oil/gas fired boilers. Emissions from these units are affected by wood/sludge fuel characteristics and particularly moisture content, boiler load, firing technique, combustion efficiency, furnace geometry, amount of refractory, overfire air design and the oil or gas burner capacity and usage. All are important factors in determining the aggregate emissions.

Several measures considered for controlling NO_x emissions from power boilers are summarized in Table C - 9 for existing power boilers.

Table C - 9: Power Boiler NO_x Emission Control Measures

Overfire Air System Upgrade	Low NO_x Burners	Selective Non Catalytic Combustion
Description:		
Installation of large overfire air ports, dampers, & controls.	Replacement of older standard burners with newer staged combustion designs.	Injection of ammonia or urea into a high temperature section of the furnace
Applicability and Prevalence:		
Wood only and combination wood and fossil fuel water wall boilers with small ports, and poor furnace mixing, in units often built before 1980.	Combination wood and fossil fuel boilers and fossil fuel only fired boilers with older standard burners. Moderately common in new installations.	Most wood only and combination wood and fossil fuel field erected boilers. Very rare. Applied in some US locations where AAQ does not meet federal or local standards.
Primary Justification and Benefits:		
Improved furnace mixing and combustion, reduced emissions, reduced fossil fuel usage[a].	Lower support fuel NO_x emissions.	Reduces NO_x once formed to N_2.
Potential Emission Reduction Assumed		
NO_x: 20-40 ng/J. Also some CO, PM, VOC (and TRS if NCG fired in furnaces with very poor mixing).	NO_x: 40-60 ng/J. Possibly CO and VOC reductions as well.	NO_x: 20-50 ng/J.
Constraints and Considerations		
Prediction of emission reduction uncertain; unlikely suitable for some very old boilers.	Reduced proportion of fossil to wood fuel usage undermines justification.	Uncertain prediction of emission reduction. If NH_3 used: transport of a hazardous material.

Note:
a - Reduced fossil fuel usage is often achieved, and an important driver for such upgrades. The estimates presented here do not include the effect of reduced fossil fuel usage on emissions or economics which may be significant.

The cost of these NO_x control measures for existing power boilers is presented in Table C - 10.

Table C - 10: Power Boiler NO_x Emission Control Costs[a]

Air System Upgrade	Low NO_x Gas Burners	Selective Non Catalytic Reduction
Existing older boiler	**Existing older boiler**	**Existing older boiler**
Capital Costs, in M$		
0.2-0.7	0.3-1	0.5-1.4
Annualized Capital Cost in k$/a		
40-100	50-160	80-220
Operating Cost in k$/a		
100-180	110-200	230-440
Annualized total cost of Control Measure in k$/a		
140-300	160-360	300-660
Annualized total cost of Control Measure, $/GJ heat input		
0.06-0.12	0.07-0.14	0.13-0.24
Pollutant Removal Costs, $ per tonne		
NO_x as NO_2: 1500-4000	NO_x as NO_2 1000-2300[b]	NO_x as NO_2 2700-12,000

Notes: a - Order of Magnitude costs for the equipment described in Table D - 9. See section Basis of Cost Estimates.
b - Assuming continuous operation for 350 d a, otherwise costs will be inversely proportional to use per year.

To give some idea of these costs of control in terms of production, consider an 800 ADt/d kraft pulp mill with a power boiler generating 125 t/h steam from wood. Such a power boiler will have a heat input from wood of about 480 GJ/h so that the costs become: $0.9-1.8/ADt for an

overfire air system upgrade; $1-2./ADt for low NO_x burners where burner usage is continuous; $2 - 3.4/ADt for selective non-catalytic reduction.

A number of other modifications would also be expected to improve emissions such as grate replacement, firing wood fuel of improved quality, wood fuel drying, and reduced use of supplemental fossil fuel. The amount that these changes have on air emissions requires the involvement of vendors for a careful analysis of the specific details of the boiler system. There will typically be a degree of uncertainty associated with the predictions of emission reduction, and the suppliers may not be willing to provide emission reduction guarantees.

For controlling particulate emissions, the electrostatic precipitator is currently the preferred control device in new facilities for its high availability and efficiency. A further advantage is that water is not added to the flue gas as occurs in wet scrubbing which increases plume opacity. Bag houses have not gained wide acceptance because of concerns regarding bag life and the risks of downtime due to catastrophic bag failure following fires in the collected particulate matter. Multiple cyclones and most types of wet scrubbers represent older technology, and are considerably less costly even allowing for treatment of the scrubbing medium in the case of wet scrubbers. However, they are unable to come anywhere close to meet the emission limits for current best practice.

The measures presented in Table C - 11 are applications for electrostatic precipitators in an existing power boiler and in a new greenfield mill. The approach to upgrade the existing precipitator is to divert 1/3 of the flow into a new ESP casing and upgrade the internals of the original ESP with an improved gas distribution screen, rigid emitting electrodes and voltage/current controllers. For reference, the new greenfield mill case considers the cost of adding more collection area to the ESPs at the beginning of design. Both cases are to give an outlet emission of 30mg/SDm^3 at 7% O_2. The corresponding costs are shown in Table C – 12

Table C - 11: Power Boiler PM Emission Control Measures

Electrostatic Precipitator Upgrade	
Existing Older Power Boiler	**New Greenfield Power Boiler**
Description	
Upgrade of existing ESP (rigid electrodes, controls), and addition of new single chamber ESP for 1/3 of the flow.	Increased removal efficiency by increasing collection area by 18%.
Applicability and Prevalence	
Power boilers built before the mid-1980s.	This expenditure would probably be made in areas where PM is of concern in Canada.
Primary Justification and Benefits	
Reduction of PM emissions, reduced downtime and possibly maintenance.	Reduced PM emissions.
Potential emission Reduction Assumed	
No limit to reduction of PM and PM_{10} by adding collecting area. This example assumes reduction from 225 to 30 mg/SDm^3 at 7% ref. O_2, about 120 ng/J.	No limit to reduction of PM and PM_{10} by adding collecting area. This example assumes reduction from 50 to 30 mg/SDm^3 at 7% ref. O_2, about 10 ng/J.
Constraints and Considerations	
High costs due space limitations in many cases. Mill specific studies required to reduce cost uncertainty.	Need to specify the emission level very early in the design process. Cost.

Table C - 12: Power Boiler Emission Control Costs[a]

Electrostatic Precipitator Upgrade	
Existing older boiler	**New Greenfield boiler**
Capital Costs, in M$	
2-6	0.4-0.8
Annualized Capital Cost in k$/a	
350-1000	70-130
Operating Cost in k$/a	
130-400	30-60
Annualized total cost of Control Measure in k$/a	
470-1400	100-180
Annualized total cost of Control Measure, $/GJ	
0.36-0.83	0.05-0.06
Pollutant Removal Costs, $ per tonne	
PM	PM
6400-15,000	1900-6700

Notes: a - Order of Magnitude costs for the equipment described in Table D - 11. See section Basis of Cost Estimates.

Again, to give some idea of these costs of control in terms of production, consider again the case of an existing 800 ADt/d kraft pulp mill with a power boiler generating 80 t/h steam from wood with a heat input of about 280 GJ/h. Replacement of the existing control system to an electrostatic precipitator would cost $3-5/ADt. For a new 1,500 ADt/d greenfield mill with a power boiler heat input of about 520 GJ/h, upgrading at the time of specification of the precipitator to provide control to 30 mg/SDm^3 instead of 50 mg/SDm^3 would cost $0.9/ADt.

C - 9 Effluent Treatment

Effluent contains VOCs and HAPs, and in the case of kraft mills, TRS as well. A large proportion of these compounds are released from exposed surfaces such as in the effluent collection and treatment system and are a diffuse source of emissions. The amounts emitted can be very significantly reduced by steam stripping the contaminated evaporator process and digester condensates (blow tank, turpentine condenser) before reuse and their eventual discharge to sewers and the effluent treatment system.

Another very important source of TRS emissions is generated within the effluent treatment system itself from the action of anaerobic bacteria on the sulphur compounds in the effluent where flows stagnate or recirculate and insufficient oxygen is available. This source of sulphur compounds may include some TRS sources but mainly is the sulphur in black liquor and any sulphuric acid from the ClO_2 and other plants.

The steam stripper uses a distillation column to concentrate the VOCs, TRS and other gases in a small vent flow which is then incinerated. This technology does not reduce the TRS emissions resulting from the action of anaerobic bacteria. Modern designs using a steam-to-feed ratio of 18-20% remove about 94% of the TRS, 90% of the methanol, and 90-99% of a number of other HAPs. As the stripper off gases are eliminated by incineration, stripping makes an effective TRS, VOC and HAP method of control in all chemical or mechanical pulping processes.

Retrofitting a steam stripper in an existing kraft pulp mill for control of TRS originating from the process condensates is presented in Table C - 13. The order of magnitude estimates of cost corresponding to these measures are presented in Table C - 14. The cost of operating the CNCG system benefits from the fuel credit of the methanol recovered and burned. It is assumed that disposal will be in the lime kiln where it will displace fossil fuel fired there; if disposal is in a wood-fired power boiler, some wood fuel may be displaced if the fossil fuel is used as support fuel and a smaller credit than that assumed in the example presented would result.

Table C - 13: Effluent Treatment TRS Emission Control Measures

Scrubber Upgrade **Existing older mill**
Description: Installation of a stand-alone steam stripper for evaporator and digester foul condensates. It assumes that capacity for incineration is available in the kiln. **Applicability and Prevalence:** Kraft recovery mills built before the early 1970's. A significant proportion of the kraft mills in Canada have no steam stripper. **Primary Justification and Benefits:** Reduction of TRS, VOC and HAPs emissions as well as BOD_5 reducing effluent treatment aeration horsepower. **Potential Emission Reduction Assumed** TRS: 0.6-1.3 kg as H_2S/ADt. VOC: 1.0-1.5 kg as CH_3/ADt **Constraints and Considerations** High retrofit and energy consumption costs, though if integration of the stripper into an evaporator is practical, steam will be saved. The addition of a stripper will not reduce the TRS emissions from the effluent treatment system that originate from the action of anaerobic bacteria.

Table C - 14: Effluent Treatment TRS Emission Control Costs[a]

	Steam Stripping Existing older mill
Capital Costs in M$	2.8-9
Annualized Capital Cost in k$/a	400-1400
Operating Cost in k$/a	1300-3500
Annualized total cost of Control Measure in k$/a	1800-4900
Annualized total cost of Control Measure in $/ADt production	15-20
Pollutant Removal Costs, $ per tonne	
TRS as H_2S:	38,000-200,000
VOC as CH_4/ADt	9,000-17,000

Notes: a - Order of Magnitude costs for the equipment described in Table d - 13. See section Basis of Cost Estimates for details.

A favoured approach in Scandinavia is the addition of a methanol rectification section in the column to produce methanol of high purity, though relatively expensive. This is a good fuel that is liquid at ambient temperatures, and as convenient to store and fire as light oil. However, this addition does not affect the TRS or VOC emission reductions.

C - 10 Comparison of Estimated Cost per Tonne Contaminant Removed

Figure C - 1 presents a summary of all the preceding cost per tonne removed estimates on a single graph which allows quick identification of the most cost effective reduction project. Because of the wide range of values for $/t removed, the log scale is used for the abscissa. As a host of assumptions have been made to develop these estimates, such as the emission level before the measure is applied as well as the level after the controls are in place, the optimum project for an actual mill may well be outside the range of $/t removed shown.

From Figure 4.2, it is seen that the best projects for:

- PM reduction are ESP retrofits for the recovery and power boilers and scrubber upgrade for smelt dissolving tank
- NO_x reduction is an air system upgrade and low NO_x burners on the power boilers.
- TRS and VOC reduction are CNCG systems, next steam stripping, then dilute NCG systems

Of all the air emission contaminants emitted by the industry, odorous TRS gases continues to have the highest profile and be the source of most of the complaints. The most cost-effective TRS project is to upgrade the concentrated NCG system to comprehensively collect all remaining concentrated sources and provide for their disposal in a lime kiln, stand alone incinerator with an SO_2 scrubber, power boiler, or, as is standard practice in new mills today, in the recovery boiler. The large diameter ductwork required to collect DCG sources is significantly less cost-effective.

A number of the control measures simultaneously reduce emissions of more than one type. An example is a TRS collection system that simultaneously captures VOCs as well. Other examples are: the upgrade of a recovery air system which reduces NO_x, TRS, CO and VOC; a low odour conversion of a recovery boiler which reduces NO_x, CO, SO_2, TRS, and VOC Care must be taken in aggregating measures for a given mill or across the industry, to avoid double counting.

One caution to emphasize about the data presented in Figure 6-1: changes to the emission reduction assumptions selected to develop the costs, or cost estimates developed for specific mill situations will shift the cost per tonne and the relative ranking of the "best" project. The results, however, are believed to illustrate how the costs may relate among options.

As already stated, the foregoing results and comparison should be considered illustrative only and preliminary in nature. The optimal control project for any one mill depends on many factors which generally require a significant amount of engineering to be properly evaluated.

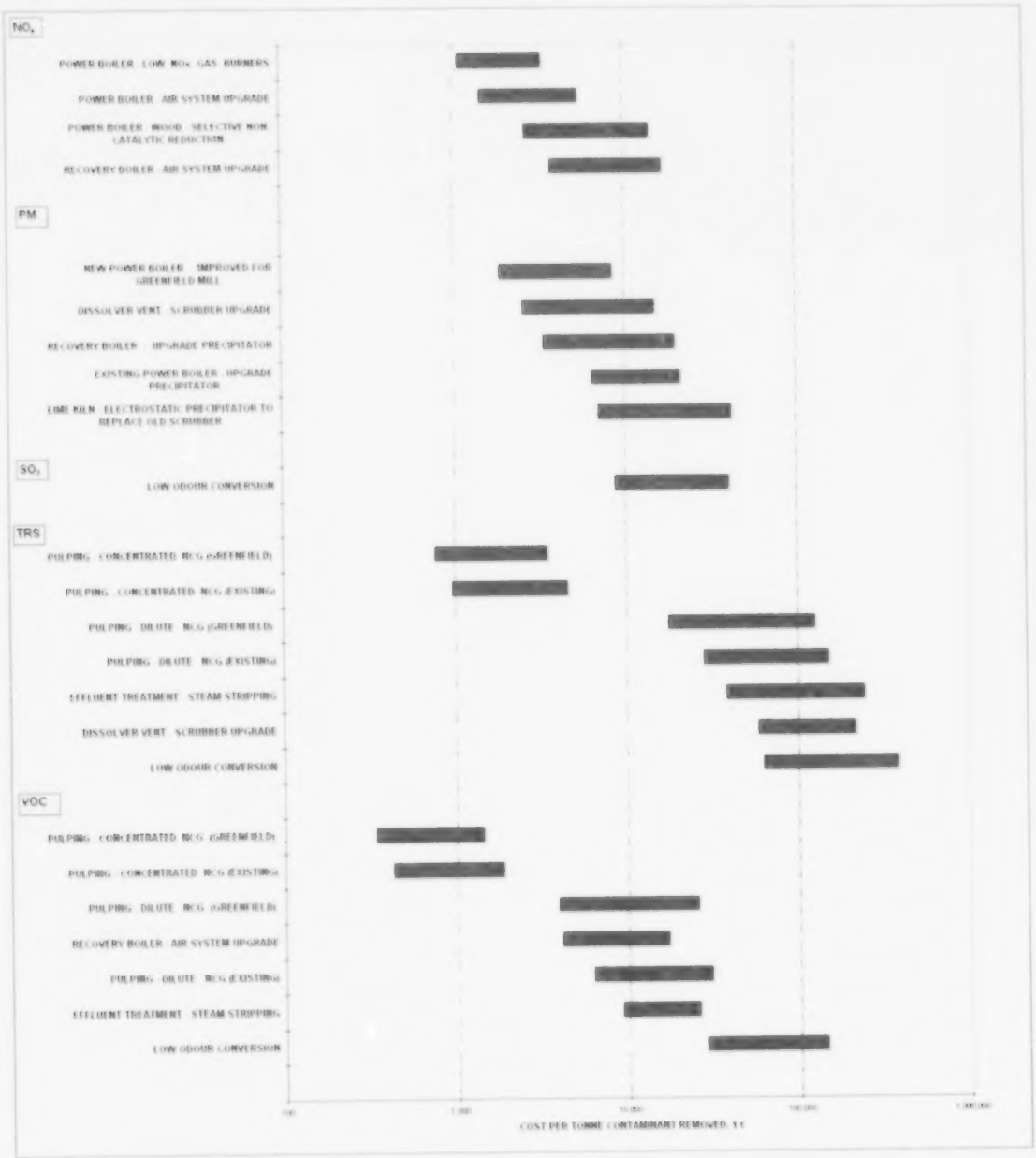
NOx
POWER BOILER - LOW NOx GAS BURNERS
POWER BOILER - AIR SYSTEM UPGRADE
POWER BOILER - WOOD - SELECTIVE NON CATALYTIC REDUCTION
RECOVERY BOILER - AIR SYSTEM UPGRADE
PM
NEW POWER BOILER - IMPROVED ESP (GREENFIELD MILL
DISSOLVER VENT - SCRUBBER UPGRADE
RECOVERY BOILER - UPGRADE PRECIPITATOR
EXISTING POWER BOILER - UPGRADE PRECIPITATOR
LIME KILN - ELECTROSTATIC PRECIPITATOR TO REPLACE OLD SCRUBBER
SO2
LOW ODOUR CONVERSION
TRS
PULPING - CONCENTRATED BCG (GREENFIELD)
PULPING - CONCENTRATED BCG (EXISTING)
PULPING - DILUTE - BCG (GREENFIELD)
PULPING - DILUTE - BCG (EXISTING)
EFFLUENT TREATMENT - STEAM STRIPPING
DISSOLVER VENT - SCRUBBER UPGRADE
LOW ODOUR CONVERSION
VOC
PULPING - CONCENTRATED BCG (GREENFIELD)
PULPING - CONCENTRATED BCG (EXISTING)
PULPING - DILUTE - BCG (GREENFIELD)
RECOVERY BOILER - AIR SYSTEM UPGRADE
PULPING - DILUTE - BCG (EXISTING)
EFFLUENT TREATMENT - STEAM STRIPPING
LOW ODOUR CONVERSION
COST PER TONNE CONTAMINANT REMOVED, $

Figure C - 1: Contaminant Removal Cost per tonne for Selected Generic Emission Reduction Measures by Emission Type – Illustrative Examples

APPENDIX D – Conversion of Units

APPENDIX D - CONVERSION OF UNITS

D - 1 *Introduction*

Emissions are expressed in terms of concentration by weight or mass, eg: parts per million, or in terms of throughput as in kg/ADt referencing production, kg/tBLS black liquor, or ng/J gross fuel heat. Therefore the conversion of emissions from one set of units to another is essential to allow comparison, particularly in a report such as this. It is not possible for conversions to be exact in all cases, because of differences in process and material compositions.

The main body of the report presents the emission data as it appears in the literature source, be it based on concentration or throughput.

D - 2 *Standard Dry Conditions*

Standard conditions of temperature and pressure are not unique, but require definition, as they vary among industries and jurisdictions. Standard conditions adopted for the report are 20°C and 101.325 kPa which is equivalent to 68°F and 760 mm of mercury. British Columbia, the US EPA and the US states use the same standard temperature, while Alberta, Quebec and the Federal Government regulations use a standard temperature of 25°C. Outside North America and in science generally, standard temperature is 0°C and the same pressure, called normal conditions and designated N. Normal temperature is a unique value and only means 0°C, whereas standard temperature has to be defined.

Concentrations are often most useful when expressed on an equivalent basis. These are normally at standard (S) conditions and dry (D) basis as moisture content generally varies from one source to another, interfering with comparison. When manipulating emission data, volumetric flow rate is also converted to standard dry conditions.

Example: to correct 100 actual cubic metres per second (Am^3/s) at an elevation of 320 m equivalent to an atmospheric pressure of 735 mm Hg, a temperature of 192°C and moisture content of 23% by volume, to standard dry conditions:

$$100\,\frac{Am^3}{s} \times \frac{(273+20)}{(273+192)} \times \frac{732\,mmHg}{760\,mmHg} \times \frac{(100-23)}{100} = 46.73\,\frac{SDm^3}{s}$$

where standard (S) conditions are 20°C and 760 mm Hg (101.325kPa), and dry (D).

D - 3 *Volume to Weight*

The conversion of a mass-volume concentration in mg/SDm^3 to a volume-volume concentration in parts per million dry basis designated ppm_{DV} is made directly noting that an amount of any gas corresponding to the molecular weight in kilograms, or kg-mol, occupies the same volume at the same pressure and temperature. For frequently uses standard temperatures the mol volume is:

Temperature	kg mol volume (SDm^3/kg-mole)	Jurisdictions
0	22.41	Europe, other
20	24.05	US EPA, US States, BC
25	24.46	AB,QC, Federal Canadian

An example is the conversion of 100 mg/SDm^3 of SO_2 in a European document to US EPA units of ppm_{DV}, recognising 22.41 SDm^3 of SO_2 weighs 64 kg:

$$100\frac{mg}{NDm^3} \times \frac{22.41\,NDm^3}{64\,kg\ of\ SO_2} \times \frac{10^{-6}\,kg}{mg} \times \frac{ppm_{dv}}{10^{-6}} = 35.0\,ppm_{dv}$$

D - 4 *Reference Oxygen*

Combustion sources require an additional reference condition. Concentrations whether by weight or volume require adjustment for the various excess air levels commonly found in flue gases to allow comparison of concentrations without the distortion presented by dilution air. This report adopts the US EPA reference oxygen values of 8% for recovery boilers, 7% for power boilers, and 10% for lime kilns all by volume on a dry basis. An example of a conversion to reference oxygen conditions for a recovery boiler:

$$100\frac{ADm^3}{s}\ at\ 2.3\%\,O_2 = 100 \times \frac{(21-2.3)}{(21-8)} = 143\frac{ADm^3}{s}\ at\ 8\%\,O_2$$

Sometimes, power boiler emissions are expressed in terms of a reference content of CO_2, rather than O_2. As a reasonable approximation to convert one system to the other, it is noted that the sum of the volumetric percents of O_2 and CO_2 total about 19.5 - 20.5. Thus, the commonly adopted equating of 12% CO_2 to 7% O_2 is reasonably close, and is used in this report.

D - 5 *Specific Flue Gas Volume Rates*

D - 5.1 Power Boilers

For reasons that are beyond the scope of this study, the dry volume of flue gas at standard temperature and pressure depends little on the wood species or sludge type for preliminary engineering analysis. This is also approximately true, but to a lesser degree, for black liquor combustion where liquor analysis can vary more widely. Accurate estimates require a complete analysis to establish all the major components in the flue gases. This is obtained in a combustion calculation based on the elemental analysis of the fuel and the excess air.

The US EPA identifies approximate estimating factors as "F" factors, presenting them at 0% O_2 by volume reference conditions, differentiating between wood and bark, as follows:

$F_{d\text{-}wood}$ = 248 SDm^3/GJ
$F_{d\text{-}bark}$ = 258 SDm^3/GJ
$F_{d\text{-}gas}$ = 243 SDm^3/GJ
$F_{d\text{-}oil}$ = 248 SDm^3/GJ
$F_{d\text{-}coal}$ = 263 SDm^3/GJ (Bituminous)

where standard (S) conditions in this case are 20°C and 760 mm Hg (101.325kPa, and dry (D) (CFR-40, 1989, p900). These relations are more useful when adjusted to the appropriate reference oxygen and using an average composition and higher heating value on a dry basis for bark and wood; they become for the principal fuels:

Source	Specific Volume
Power boiler - wood, hog , sludge	380 $S_{20}Dm^3/GJ$ at 7 % oxygen
- gas	365 $S_{20}Dm^3/GJ$ at 7 % oxygen
- oil	370 $S_{20}Dm^3/GJ$ at 7 % oxygen
- coal (Bit.)	395 $S_{20}Dm^3/GJ$ at 7 % oxygen

D - 5.2 Recovery Boilers

The National Council for Air and Stream Improvement (NCASI) uses a similar relationship for recovery boilers, with a factor of 9000 dscf at 0% O_2/MBtu which converts to 390 SDm^3/GJ at 8% oxygen (NCASI #650, 1993, p4). However, a recent softwood mill design has a value 86%

of this amount (336 SDm^3/GJ at 8% oxygen), and a hardwood mill has a value of 80% of the above amount (316 SDm^3/GJ at 8% oxygen) when based on the higher heating value on a dry basis. Where insufficient data is available to make a direct conversion, this report has adopted the NCASI standard value of 390 SDm^3/GJ at 8% oxygen for recovery boilers. For more detailed analyses and mill specific applications, estimates of actual relationships must be developed for better accuracy.

NCASI also relate the heat content to the bone dry black liquor solids (BLS) and production with the following approximations: 3000 lbBLS/ADT and 6000 Btu/lbBLS. These provide further approximate conversions relating concentration to tBLS and ADt production.

When adjusted to the appropriate reference oxygen, the conversions are:

Source	Specific Volume
Recovery boiler	390 $S_{20}Dm^3$/GJ at 8 % oxygen
	5445 $S_{20}Dm^3$/BDt BLS at 8 % oxygen
	8170 $S_{20}Dm^3$/ADt at 8 % oxygen

D - 5.3 Smelt Dissolving Tank

Because the entry of air into the smelt dissolving tank is highly variable, the use of ppm_{DV} for comparison is of little use, though it is noted that the sampling basis is concentration. An informal survey of values in a reference show values ranging from 200 - 1200 SDm^3/tBLS (NCASI #646, 1993, p25). The average of several projects in the early 90s indicate a value of 470 SDm^3/tBLS at actual oxygen content.

Because of this variability, the emissions of smelt dissolving tanks are made in units of kg/tBLS. Conversions between tBLS and production use the same values as for recovery boilers, i.e.: 1.5 tBLS/ADt pulp whether bleached or unbleached.

D - 5.4 Lime Reburning

In the absence of kiln specific information, NCASI in the past have assumed an energy consumption of 8 x 10^6 Btu/T of reburned lime product, CaO. Though this value is valid for older kilns, newer kilns would be more energy efficient and heat consumption would generally be below 6 x 10^6 Btu/T (78 GJ/t CaO). The value of 550 lb CaO/ADT (275 kg CaO/ADt) used by NCASI is also adopted here. However, no relationship is presented to allow one to relate gas

flow in SDm^3 to tonnes of CaO throughput, perhaps as such values vary widely among the existing kilns used in industry.

Using an approximation from 1990s projects and representative for newer kilns, a value for the flue gas flow of 0.065 $Am^3/s/t$ CaO per day (125 ACFM/T CaO per day) is used. Making assumptions on temperature and moisture, these conversions become:

Source	Specific Volume
Lime Kiln	560 $S_{20}Dm^3$/GJ at 10% oxygen
	1075 $S_{20}Dm^3$/ADt at 10% oxygen
	3900 $S_{20}Dm^3$/t CaO at 10 % oxygen

These emissions are frequently expressed as ppm_{DV}, but require information on dry gas flow rate for determination of mass emission rate and comparison between mills on a kg/ADt basis.